Use and Calibration of a Quantitative Acoustic System on a Commercial Fishing Vessel

M.R. Wyeth, R.D. Stanley, R. Kieser, and K. Cooke

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9R 5K6

2000

Canadian Technical Report of Fisheries and Aquatic Sciences 2324

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Canadian Technical Report of Fisheries and Aquatic Sciences

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100-07278/

Canadian Technical Report of
Fisheries and Aquatic Sciences 2324

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USE AND CALIBRATION OF A QUANTITATIVE ACOUSTIC SYSTEM ON A COMMERCIAL FISHING VESSEL

by

M.R. Wyeth[1], R.D. Stanley, R. Kieser, and K. Cooke

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9R 5K6

[1]128 Wellington Ave.
Victoria, British Columbia
V8V 4H7

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Cat. No. FS 97-6/2324E ISSN 0706-6457

Correct citation for this publication:

Wyeth, M.R., R.D. Stanley, R. Kieser, and K. Cooke. 2000. Use and calibration of a quantitative acoustic system on a commercial fishing vessel. Can. Tech. Rep. Fish. Aquat. Sci. 2324: 46 p.

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ABSTRACT

Wyeth, M.R., R.D. Stanley, R. Kieser, and K. Cooke. 2000. Use and calibration of a quantitative acoustic system on a commercial fishing vessel. Can. Tech. Rep. Fish. Aquat. Sci. 2324: 46 p.

Fisheries and Oceans Canada staff, in collaboration with the Canadian Groundfish Research and Conservation Society, examined the possibility of using the acoustic systems aboard commercial fishing vessels to derive quantitative biomass estimates of widow rockfish (*Sebastes entomelas*). We deployed a portable FEMTO acoustic logging and analysis system on a commercial trawler and conducted simultaneous linear transects between the commercial trawler and a conventional research vessel.

We found that installation, calibration, and operation of the data logger onboard the commercial vessel was feasible, efficient, and practical. However, unlike the research vessel, acoustic recordings from the commercial vessel were severely affected by poor weather and sea conditions. Intercalibration results were equivocal from the limited data collected during moderate weather conditions. An overall comparison of individual backscatter values showed no major difference between vessels. A Ratio of Logs test, which compared cumulative transect backscatter, also indicated no significant difference between vessels. However, there appeared to be a significant interaction between the two main effects of vessel and position (leading or following). This appeared to be generated by a trend towards higher values being recorded when the Viking Storm was leading. The small sample size and unbalanced design resulting from poor weather, and the large variance limited the power of the analysis.

Although reasonable agreement was found it highlights the typically large variability that is observed and the often unfavourable fish distribution and weather conditions that impede these operations. Our results indicate that intercalibration can provide a meaningful overall comparison. However quantitative measurements essentially must rely on the quality, calibration and long-term stability of the acoustic system. A proven acoustic system that does not depend on the vessel sounder or other unknown components is therefore required.

Given such a system the concept of using adapted commercial vessels for stock assessment and quantitative acoustic research of rockfish appears feasible. However, the acoustic measurement is only one component. Careful work and collaboration between parties will be required to develop guidelines for the appropriate and timely coverage of the survey area and to development the significant analytical infrastructure that will be required to process the data, especially if many vessels are involved.

RÉSUMÉ

Wyeth, M.R., R.D. Stanley, R. Kieser, and K. Cooke. 2000. Use and calibration of a quantitative acoustic system on a commercial fishing vessel. Can. Tech. Rep. Fish. Aquat. Sci. 2324: 46 p.

Des membres du personnel de Pêches et Océans Canada ont collaboré avec la Canadian Groundfish Research and Conservation Society pour examiner la possibilité d'utiliser le système acoustique installé à bord des bateaux de pêche commerciaux pour effectuer des estimations quantitatives des effectifs de veuves (*Sebastes entomelas*). Nous avons installé un système portatif d'enregistrement et d'analyse acoustique FEMTO sur un chalutier commercial et avons effectué des transects linéaires simultanément à partir de ce bateau et à partir d'un navire de recherche conventionnel.

Nous avons pu établir que l'installation, l'étalonnage et l'utilisation de l'enregistreur de données à bord du bateau commercial étaient faisables, voire relativement aisés. Cependant, à la différence des mesures effectuées sur le navire de recherche, les données acoustiques enregistrées à partir du bateau de pêche commercial ont été sévèrement dégradées lorsque les conditions météorologiques ou l'état de la mer étaient mauvais. Les étalonnages comparatifs n'ont donné que des résultats équivoques à cause du nombre limité de données recueillies dans des conditions météorologiques modérées. Une comparaison globale de chaque valeur d'intensité rétrodiffusée a cependant montré qu'il n'y avait pas de différence importante entre les signaux recueillis par les deux bateaux. Un test comparant les signaux rétrodiffusés cumulés a également indiqué que les enregistrements des deux bateaux ne différaient pas de façon importante. Il semble néanmoins que la position relative des navires ait un effet important sur les mesures. On a observé ainsi un signal plus élevé lorsque le Viking Storm était en tête. La petite taille de l'échantillon, des conditions expérimentales déséquilibrées dues au mauvais temps et une variance élevée ont limité la portée de l'analyse.

Bien que l'on ait constaté un accord raisonnable entre les deux enregistrements, l'expérience a mis en lumière la variabilité importante typique de ces mesures et les difficultés provenant d'une distribution des poissons et de conditions météorologiques souvent défavorables. Nos résultats montrent qu'un étalonnage comparatif peut fournir une comparaison d'ensemble pertinente. Les mesures quantitatives doivent cependant dépendre pour l'essentiel de la qualité, de l'étalonnage et de la stabilité à long terme du système acoustique. Il est donc nécessaire d'installer un système éprouvé qui ne dépende pas de la sondeuse du bateau ou d'autres composants mal connus.

En admettant qu'un tel système puisse être installé, l'idée d'utiliser des bateaux commerciaux ainsi équipés pour l'évaluation des stocks de sébastes et la réalisation de relevés acoustiques quantitatifs semble réalisable. Les mesures acoustiques elles-mêmes ne représentent néanmoins qu'une étape. Les parties intéressées devront collaborer étroitement pour préparer des directives facilitant la couverture appropriée et opportune des secteurs étudiés et l'élaboration d'une infrastructure analytique suffisamment sophistiquée pour traiter l'ensemble des données, en particulier si plusieurs bateaux participent à ce type d'opération.

INTRODUCTION

Work by Wilkins (1986) and Stanley *et al.* (2000) has shown that scientific echosounders aboard large research vessels can be used to estimate the biomass of off-bottom shoals of widow rockfish (*Sebastes entomelas*, Jordan and Gilbert 1880). However, the operating cost of these vessels limits the extent of acoustic work and the difficulty of scheduling makes it impossible to respond rapidly to unexpected appearances of large shoals.

Most commercial fishing vessels now use echosounders, sonar, and precise navigation equipment (GPS) in their daily fishing activities to locate fish, project catch rates, and set their gear (Misund 1997). Thus, relatively little additional equipment is required for these vessels to collect geo-referenced digital acoustic data that can provide a permanent record of fish abundance. The practicality of adapting commercial fishing vessels to supplement and possibly replace research platforms for acoustic surveys has already been successfully demonstrated in Canadian herring assessments (Melvin *et al.* 1998). They showed that such vessels can serve as viable alternatives to government research vessels. In addition to scheduled use of these platforms, commercial vessels can provide "opportunistic" sampling when significant acoustic signs of fish are encountered during routine fishing.

We explored the potential of involving Pacific coast fishers and the acoustic systems on their vessels in groundfish stock assessment research by conducting a joint commercial and research vessel-based acoustic survey of widow rockfish from January 15 to February 8, 1999. The goals of this study were to:

1) test the feasibility of installing a hybrid echo-integration system that used a specialised portable digital data logging system in conjunction with the existing echosounder and transducer aboard a commercial fishing vessel;
2) examine the practicality of system installation, testing and calibration prior to use in an acoustic survey;
3) examine the performance of this system during various weather conditions and with various fish densities;
4) conduct an intercalibration between this system and a scientific system (SIMRAD EK500) aboard a research vessel;
5) introduce the practice of acoustic data collection and interpretation to trawl fishers.

This report summarizes the deployment, operation and intercalibration of the acoustic data logging and analysis system aboard a commercial fishing vessel. It is not to be construed as a review of acoustic hardware or software.

MATERIAL AND METHODS

SURVEY VESSELS AND ACOUSTIC EQUIPMENT

The vessels used in this survey were the CCGS W. E. Ricker, a 57.3 m Fisheries and Oceans, Canada research trawler, and the MV Viking Storm, a 31.7 m commercial trawler. The acoustic system on the W. E. Ricker was based on a SIMRAD EK500 38/120 kHz split beam echosounder (7° beam width), a SIMRAD BI500 data logging and analysis system, and three colour printers used for echogram display and recording. In addition, we employed a PC-based analysis system that included navigation and charting software (Seaplot, Advanced Marine Technology Corp 1993) and a geographic information system (CompuGrid, Langford 1996) for mapping and spatial analysis. The transducers were mounted on a single retractable ram located mid-ships. All survey work was conducted with the ram fully extended to a transducer depth of 4.3 m, 1.4 m below the keel.

The acoustic system on the Viking Storm was based on a Furuno FCV261 50 kHz echosounder and a Furuno 50B12 hull-mounted transducer (12° beam width) interfaced to a FEMTO 9001 digitizer. A PC-based FEMTO Hydroacoustic Data Processing System (HDPS) acquired and combined data from the digitizer and a Furuno GP-35 GPS. Data logging was conFigd such that recording could be initiated at the beginning of each transect and terminated following the completion of a transect. The HDPS was installed on a second computer that was used for real-time echo editing, integration, and data processing. The Viking Storm was also equipped with a 28 kHz Furuno echosounder but data from this echosounder were not recorded. Although little interference was observed between the sounders, the 28 kHz unit was generally not used while logging data.

The echosounders on the W. E. Ricker and Viking Storm used 38 and 50 kHz frequencies, respectively. Target strength, or backscatter cross-section of fish, has a weak dependence on the echosounder frequency (Misund 1997, McClatchie *et al.* 1996). Given the large variability of observed and published target strengths (MacLennan and Simmonds 1992), we chose to ignore the relatively minor impact of the different frequencies on the estimates. For the remainder of the document, we refer to the Viking Storm/Furuno/FEMTO and the W. E. Ricker/SIMRAD acoustic logging, editing, and processing systems by vessel name only.

ECHOSOUNDER CALIBRATION

Calibrations for both vessels followed procedures outlined by Foote *et al.* (1987). The calibration for the W. E. Ricker was conducted on January 31, 1999 in Hardy Bay. Precision copper spheres of 23.0 and 60.0 mm diameters and known target strengths of -40.4 and -33.6 dB were used for the 120 and 38 kHz echosounder channels, respectively. Spheres were thoroughly cleaned with soapy freshwater and submerged below the transducers for one hour prior to data collection. The calibration was conducted with the transducer ram retracted to minimize the risk of entangling suspension lines during deployment and retrieval of the spheres.

The calibration for the Viking Storm was conducted January 15, 1999 near the Pacific Biological Station in Nanaimo. A 38.1 mm tungsten carbide sphere with a known target strength of -41.0 dB was suspended under the single beam transducer. The sphere calibrations and an additional time varied gain (TVG) calibration were performed at a number of different sounder settings in the event that one set of settings proved to be superior to the default settings. Additional information on the FEMTO system calibration procedures is provided in Clay and Claytor (1998).

We did not re-calibrate the W. E. Ricker or Viking Storm after the survey. Long and short term stability of the W. E. Ricker acoustic system can be estimated from the four year calibration record that includes nine calibrations that were completed at six different locations and at water temperatures ranging from 8.0°-13.6°. The standard deviation for all calibrations is 0.25 dB (CV=6.0%), with short-term variations in a range of 0.1-0.2 dB (CV=2.3-4.7%) (Kieser et al. 1999). Similar records do not exist for the Viking Storm, however, we expected that short term variations are not much larger. We assumed that the minor gain changes would be negligible compared to the variation imposed by fish behaviour and sea conditions.

STUDY SITES AND TRANSECT DESIGN

Observations were collected from two study sites from January 15-February 8, 1999. Site 1 was located west of Triangle Island, at the edge of the continental shelf, off the northern tip of Vancouver Island, British Columbia (Fig. 1). Site 2 was located in Goletas Channel off the northeast tip of Vancouver Island, northeast of Hardy Bay. The bottom at site 1 was characterized by high relief with depths ranging from 150 to 600 m while the bottom at site 2 was relatively flat with depths of approximately 250-350 m.

The two vessels traveled the same linear transects at speeds ranging from 6-8 knots. The distance between the two vessels was generally maintained at 0.25-0.50nm. We chose the larger distance to avoid wake effects of the leading vessel when weather conditions deteriorated. It was assumed the fish aggregations were relatively stable over the resulting 2-8 minute time interval.

We conducted two series of transects at site 1. The "A" series transects were oriented from northeast to southwest, perpendicular to the "break-in-slope" at the edge of the continental shelf (Fig. 2) and the main axis of a widow rockfish shoal. Transects 1 through 11 were conducted sequentially and treated as one micro-survey. Even numbered transects were completed while travelling southwest while odd numbered transects were completed towards the northeast. At the completion of transect 11, the leading and trailing vessels switched positions and returned to the start of transect 1 to complete another micro-survey. During micro-survey 6, an additional transect (number 0) was added to confirm the northerly bounds of the fish aggregation. Transects were sometimes lengthened in response to fish densities. However, for the paired transects, both vessels always covered the same area.

The "E" series micro-survey was also conducted at site 1 but the single transect was oriented parallel to the break-in-slope at the edge of the continental shelf (Fig. 2). It passed along the main axis of the shoal by following the 170 m depth contour (Fig. 2). It was

designed to pass over the maximum possible fish densities and demonstrate the relative continuity of the shoal along its main axis. Only the W. E. Ricker completed this transect which was repeated from south to north 16 times and from north to south one time.

The "I" series micro-surveys used the same basic methodology as the A series but were completed at site 2 and consisted of two transects oriented from northwest to southeast (Fig. 3). We conducted these surveys to provide comparisons of the two systems at much lower fish densities. It also allowed us to make use of inclement weather days that prevented us from working at site 1.

Each transect was identified using the naming convention SMMNN, where S is the micro-survey series, MM is the micro-survey number, and NN is the transect number. For example, transect 02 of A series micro-survey 01 was named A0102.

DATA EDITING

Weather Effects

The quality of echogram recording is often weather dependent. Vessel and transducer motion can lead to distorted echograms and signal loss (MacLennan and Simmonds 1992). Sub-surface air bubbles from vessel motion and/or wind may be deep enough to interfere with the propagation of sound through the water column. This can result in attenuated or blocked echoes (Mitson 1983, MacLennan and Simmonds 1992, and Misund 1997).

Echograms from the W. E. Ricker appeared stable in sea conditions associated with wind speeds up to 35-40 knots but rapidly degraded at higher wind speeds. In contrast, echograms from the Viking Storm started a gradual degradation when wind speeds reached 20-25 knots (Fig. 4). Vessel pitch, roll, and heave were reflected in distorted single fish echoes and a sinusoidal bottom trace. Air bubbles below the transducers, or aeration, were responsible for vertical lines and dropouts (no signal) that could cover the entire depth range and span several pings on the echogram. Dropout was only evident in the worst weather conditions, while vertical lines started to appear in calmer conditions.

We visually qualified the paired echograms from each transect based on the amount of interference from aeration in the Viking Storm recordings (Fig. 4). Echograms for which more than approximately 5% of the pings displayed vertical lines were graded as poor. All poor paired transects were removed from the analyses. This screening attempted to remove all transects where weather and sea conditions could have significantly affected the recordings from either or both vessels. However, due to the poorer quality of the Viking Storm echograms and their gradual change, it is still possible that, even in the subset of echograms we retained, some Viking Storm recordings were affected while the W. E. Ricker recordings were not.

During harsher weather conditions at the Triangle Island study site, the Viking Storm often recorded the poorest quality echograms while travelling into the wind. Thus, under the prevailing wind conditions, we retained more echograms when the vessels were travelling shoreward, to the northwest.

Visual Echo Editing

Data and echograms gathered by the W. E. Ricker acoustic systems were edited using the SIMRAD BI500 analysis software while those from the Viking Storm were edited using the HDPS software. Both systems allow visual editing of the echograms and data processing to be conducted at sea.

To obtain comparative integrated backscatter measurements, both echograms were edited to include only a specific depth layer of fish. The detection of fish near the seabed is problematic due to the difficulty in separating fish echoes from bottom echoes (MacLennan and Simmonds 1992, Aglen 1994). This bottom "dead zone" can be substantial. Its extent depends on transducer beam-width and bottom depth, slope, and roughness. To avoid problems associated with this dead zone and any potential difference in the two systems' abilities to screen near-bottom signals, we employed a 10 m bottom buffer. Removing all signals below 10 m above the first strong bottom echo created this buffer zone. We also limited the comparison to signals above 200 m depth and below a 50 m surface buffer.

INTERCALIBRATION

Assumptions

If the acoustic systems aboard two vessels are correctly calibrated then the average backscatter measurements made over the same group of fish should be equal. This, however, assumes that:

1) the acoustic systems on both vessels are stable;
2) the acoustic signals are unaffected by vessel motion and sea conditions;
3) the leading vessel does not leave a wake that affects the following vessel's recordings;
4) fish distributions are unaffected ahead, under, or behind the vessels;
5) both vessels take random samples from the same idealised fish distribution.

Our survey methodology was designed to satisfy these assumptions. However, we realize that even agreement over a wide range of densities does not guarantee that both systems provide perfect measurements as it is conceivable that equal results are obtained due to equal or compensating biases. We attempted to detect possible violations of the assumptions by alternatively assigning vessels to the leading and following positions, but we realize that there are too many unknown factors to reliably isolate specific causes.

Analyses

Both systems recorded ping by ping digital data of the acoustical backscatter signal. Echo integration on the W. E. Ricker and Viking Storm was over distance intervals of 0.10 and 0.12 nm, or approximately 58 and 70 pings, respectively. The depth interval was 50-200 m depth or to 10 m off bottom. The HDPS echo integration output was converted so that both vessels would report the mean backscatter cross-section per horizontal area (m^2/nm^2) or Sal value for each interval.

We examined the Sal values for outliers by plotting the values from both vessels versus their longitudinal position for each micro-survey (Appendix Figs. 1 and 2). High values from either vessel were re-examined on the echograms to positively exclude bottom integration. Corrections were required in a few instances.

For pair-by-pair comparison of the Sal values from the two vessels, the acoustic measurements need to be made over the same group of fish. Due to slight variations in the two vessels' paths and the lack of synchronization of the two systems' integration intervals, we could not use the individual Sal values. However paired observations, SaT, were obtained by averaging each vessels' Sals over the paired transects (Table 1).

Given the difference in the integration intervals, the Viking Storm consistently produced fewer Sal values per transect than the W. E. Ricker (Table 2). As pointed out the differing interval lengths of the two systems precluded pairing the Sal values; but one can still compare their frequency distributions as the mean and distribution of the Sal are independent of the integration interval.

We compared the backscatter measurements from the two vessels and from the leading and following vessel using three procedures:

1) plots of the frequency distributions of the Sal values;
2) an ANOVA test (Table 1) for vessel and position effects on the entire set of log-transformed Sal values;
3) a linear comparison (Ratio of Logs) of the paired SaT values from both vessels.

Assuming that fish densities were reasonably stable over the time interval between the vessels' passage, the two vessels should produce similar SaT values for each paired transect. To avoid problems of "errors of variables" in a linear comparison of SaT values, Kieser *et al.* (1987) developed a model that compares the differences of two vessels' paired, log-transformed SaT values.

Given the average log (SaT) difference $\bar{d}$ (Table 1) between paired measurements, the estimate of the ratio, "R" of the backscatter measurements from the two vessels and its confidence interval are:

We calculated the 95% confidence limits for the ratios by using approximate values

$$R = 10^{\bar{d}} \qquad \text{confidence interval} = 10^{\bar{d} \pm t_{(\alpha, q-1)} s_d \sqrt{q}}$$

from the t-distribution of the corresponding sample size (Steel and Torrie 1960).

The Ratio of Logs test was originally developed to examine the correlation between minute-by-minute paired Sal measurements taken from synchronized echo-integrators. As previously explained, we were unable to pair the Sal values. Instead, we used the SaT values which is valid as we have simply averaged the Sal values over a larger distance.

To investigate the effect of the extremely large Sal values on the statistical analyses, both R and the ANOVA model were recalculated after excluding Sal measurements greater

than 50,000 m^2/nm^2 (see Figs.. 5-8). We chose values >50,000 because this represented the approximate maximum observed by the W. E. Ricker during the comparable transects.

RESULTS

FEMTO SYSTEM INSTALLATION AND OPERATION

Prior to installation of the FEMTO system, the specifications of the Viking Storm's sounder were forwarded to the installation team to assure compatibility between the sounder and the HDPS data acquisition system. Installation of the FEMTO analogue to digital converter, the computers, and the HDPS logging and editing software took approximately 12 hours. This was followed by an additional eight hours of calibration. The system is designed to run unattended, however, we opted to employ an operator to note transect locations and other information to ensure data quality and simplify the subsequent analysis. A computer literate person required approximately 8 hours of self-training to become sufficiently proficient with the HDPS software for data acquisition, editing, and processing

During rough weather, the 50 kHz echosounder aboard the Viking Storm occasionally recorded interference from the 28 kHz echosounder (Fig. 4A). Most of the echograms with this interference were among those discarded. For echograms that were retained, the HDPS visual echo editing process was used to selectively remove the erroneous signals prior to the integration process.

INTERCALIBRATION

Summary of paired surveys

The Viking Storm and the W. E. Ricker conducted 16 paired micro-surveys. Nine were at the Triangle Island site and involved high fish densities while the seven conducted at the Goletas Channel site examined low fish densities (Appendix Table 1, Appendix Figs. 1 and 2). Transects 1 and 2 were omitted from some of the A series micro-surveys owing to the lack of fish sign in the north-west area. Transects with poor quality echograms were discarded. In addition, some of the Viking Storm recordings were not usable due to extreme noise contamination (discussed below). This left 37 pairs of comparable transects from the A series and 14 pairs from the I series for intercalibration analysis (Table 2, Appendix Table 1).

Summary of additional, unpaired surveys

In addition to the joint surveys, the W. E. Ricker completed four A series micro-surveys and the E series micro-survey while the Viking Storm was fishing. Echosounder data were also recorded by the W. E. Ricker during the return legs (Appendix Table 1, transect 99) for A series micro-surveys 3 and 7.

Analyses

1) Sal distributions from the W. E. Ricker and Viking Storm: The Sal values from the two vessels show similar trends at each study site (Appendix Figs. 1 and 2). The overall frequency distributions are similar in that both are heavily skewed with many low values and few high values (Fig. 5). The Viking Storm system produced more high values than the W. E. Ricker, in particular, three values greater than 50,000. This resulted in a higher overall mean (Fig. 6). While the extremely high Sal values recorded by the Viking Storm during the paired transects were not indicated concurrently by the W. E. Ricker system, it provided similar values during the E series transects and the unpaired A series transects (Fig. 7).

For both vessels, the extremely high Sal values at the Triangle Island site were all recorded between 129°21" and 129°24" W which corresponds to the area of the break-in-slope, the area of maximum fish density. Furthermore, all Sal values greater than 20,000 m^2/nm^2 occurred in a similar, restricted zone of the total area covered by the transects (Fig. 8).

2) Sal distributions from leading and following vessels: When we re-arranged the observations according to whether the Sal measurement was taken in the leading or following position, we obtained a response similar to the between-vessel comparison. The skewed frequency distributions were similar between positions except for the greater proportion of high values associated with the leading vessel (Fig. 9). Consequently, the overall means differed (Fig. 10). The combination of these two univariate examinations of the Sal values implies that the combination of the Viking Storm and a leading position produced more high values, or conversely, the W. E. Ricker in a following position produced lower values.

3) ANOVA test: Although the >> cumulative<< mean Sal values differed in both the vessel (Fig. 6) and position (Fig. 10) comparisons, the ANOVA test on the log-transformed Sal values indicated that these differences were not significant regardless of whether the highest values (> 50,000) were excluded (Table 3). In contrast, the interaction term between the vessel and position was highly significant in both models. The Viking Storm had a higher mean Sal value when leading (1,343 m^2/nm^2) than when following (345 m^2/nm^2) while the W. E. Ricker had a lower mean Sal value when leading (415 m^2/nm^2) than when following (603 m^2/nm^2) (Fig. 11).

The significant interaction term indicates that at least one combination of vessel and position is significantly different than the rest of the entire data set. In theory The exact source of significance of the interaction term could be explored using an "Examination of simple effects". However, the Sals from the Viking Storm leading were made at different times than those from the W.E. Ricker leading and although we assume the fish densities to be equal at all times, the possibility exists that at different times, different densities were observed. As such, a more meaningful exploration of the interaction is through the Ratio of Logs analysis where only paired measurements were used. These were taken at the same time (see next section).

Use of the ANOVA test presumes that the log-transformation results in sufficiently normal distributions, that the Sal observations are independent random samples, and that

the variances are equal among samples. We assume that both vessels take a random sample from the same idealized fish distributions. However, it is possible that the method of one vessel following the other tends to generate measurements that are not independent. Although we expected slightly lower variance in the Sal values produced by the system with the longer integration interval, examination of the residuals indicated that the variances were approximately equal (Fig. 12). Examination of the log-transformed Sal frequency distributions and the residual normal Q-Q plot indicated that although the tails diverged from the ideal distribution, the distribution was sufficiently normal for the ANOVA test (Fig. 13).

4) Linear comparison of paired SaT values: The estimates of the vessel biases, R, provided similar results to the ANOVA test. No significant deviation from a ratio of 1:1 was found in any comparison between vessels or positions using the entire data set or with the subset with Sal values greater than 50,000 removed (Table 4, Fig. 14 and 15). Unlike the ANOVA test, the R values did not indicate the statistical significance of an interaction. However, the comparison of leading to following, when the W. E. Ricker was following and using all values, was on the cusp of significance given that the lower 95% confidence limit of the ratiowas 0.99. >>Rick: Again keep the original<<

As with the ANOVA test, the difference of logs model assumes that the log-transformed data are normally distributed. The normal Q-Q plot of the transformed SaT data validates this assumption except for small deviations at the tails (Fig. 16).

DISCUSSION

INSTALLATION AND USE OF A PORTABLE ACOUSTIC SYSTEM

Installation of the FEMTO recording system aboard the Viking Storm was seamless and required only two days for set-up and calibration. This process was facilitated by a prior exchange of information that guaranteed a suitable sounder and adequate electrical power were available on the commercial vessel. The standard target calibration was completed without difficulty and bench tests established a satisfactory TVG curve and correction for the existing sounder on the Viking Storm. Tests, however, could not ascertain that the sounder would have sufficient dynamic range to accommodate the strongest signals. Thus, sufficient dynamic range had to be assumed. This seemed reasonable as our targets were distributed over a moderate depth range and of moderate intensity.

Operation of the data logging software at sea was simple, requiring only a single key-stroke to initiate or terminate recording. The transects from which data were not recorded were due to either operator error, or, in the case of micro-survey A03, an unknown error which resulted in nonsense echograms. We suspected that a computer connection failed during rough weather so we tightened all connections and had no further problems. The actual cause of the error remains unknown.

About one full day was required to gain a working knowledge of the HDPS editor and processor. Although the user was able to complete all the required echo editing steps, some limitations were encountered. Firstly, we noted that once an echogram was edited and modified, the signals that were removed were no longer present on the visual display.

As such, if re-examination of edited echograms were desired, it would be necessary to view the initial, unedited version of the echogram. A second limitation was that the HDPS digital echogram had much lower distance-depth resolution and a less informative pre-set colour scale of echo signal intensity in comparison to the BI500 display. Finally, a problem was encountered in some of the HDPS echograms. After the initial editing of some echograms, a number of pings at the right hand border of the visual display appeared to have been edited so as not to include bottom echoes. However, upon a review of the modified echograms, it was found that these bottom echoes remained. This required re-editing using a different time scale for the echogram display so that the offending pings were no longer at the border of the screen. These limitations are typical for current echo-processing systems and indicate that additional operator experience is important. This experience is also required to provide complete mapping and interpretation of the data for biomass estimates.

RESULTS FROM THE INTERCALIBRATION

Weather Effects

Weather caused a major difference in the performance of the two vessels' acoustic systems. The ram-mounted transducers aboard the W. E. Ricker allowed survey work during more severe weather conditions than the hull-mounted transducers aboard the Viking Storm. In general terms, it appeared that the W. E. Ricker system was effective in sea conditions associated with winds of up to 35 knots and a swell height of 3-4 m. The Viking Storm system stopped providing an effective signal as winds exceeded 25 knots and swells were 2-3 m. Even under the more moderate conditions, it was apparent that the signal on the Viking Storm gradually worsened with deteriorating sea conditions while the signal on the W. E. Ricker remained relatively stable.

Even at low sea conditions, vessel pitch, roll, and heave are noted as a sinusoidal bottom trace on the echogram. Under these conditions, signal loss is relatively minor. However, as sea conditions and vessel motion increase, transducer aeration will cause severe signal loss. We noted that when we retracted the ram on the W. E. Ricker, its signal was not much better than that of the Viking Storm under the same sea conditions. Thus we assume that the ram mounting of the transducer on the W. E. Ricker largely accounted for the difference in performance. Since it will be unlikely to find a ram-mounted transducer on a fishing vessel, a towed body offers an attractive alternative. It would provide better weather performance and will allow the use of a known, calibrated transducer. It possibly could be deployed at greater depth to improve signal to noise, resolution between fish and detection of fish near bottom. A "complete" portable system would reduce installation time, increase reliability, and eliminate components with unknown performance characteristics and stability.

Intercalibration

Overall, the Sal values generated during good weather by the Viking Storm system were comparable to those generated by the W. E. Ricker. Both tended to show similar highly skewed frequency distributions characteristic of aggregating fish (Kieser *et al.* 1987). Furthermore, both systems produced similar values at similar locations and the relationship between the two vessels' average transect measurements was linear over a wide range of

Sal values. We would not expect exactly the same Sal measurements from the two vessels due to modest differences in the paths traveled and random movement by the fish prior to the arrival of the following vessel. However, we would not expect any significant difference in the overall average values or any systematic bias between the two vessels.

The Viking Storm system recorded a few extremely high values during the paired transects. Re-examination of the echogram indicated that these values were not caused by falsely including bottom echoes. Furthermore, while not observed simultaneously by the W.E. Ricker during the paired transects, the W. E. Ricker system did record similar densities during the E series micro-survey as it concentrated on areas of high fish density as well as during other, unpaired observations. Since we have no basis for suggesting that the extremely high values from the Viking Storm were incorrect and because the W. E. Ricker did record similar densities on other occasions, we did not exclude these values from the analysis.

The Viking Storm transducer had a wider beam angle so its results may be more susceptible to side-lobe interference. We noted that the area of highest fish density was at the edge of the bluff near the break-in-slope of the continental shelf. This area of extreme topographic relief is also an area where side-lobe interference is most probable. Although there was no evidence on the echogram to suggest that side-lobe contributed to the signal, this remains a possibility.

When the Sal values were compared based on vessel position, the leading vessel recorded more high Sal values in the range of 15,000 to 30,000 (Figs. 9 and 10). In addition, the extremely high values (>50,000) recorded by the Viking Storm occurred when it was leading (Fig. 11). This suggests that the combination of the leading position and the Viking Storm vessel might have a bias for higher measurements.

The ANOVA test results indicated the significance of an interaction. We did not elucidate which pairs of vessel and position were significantly different because, as previously mentioned, the results of the R test are more informative. The R test shows that the lead vessel had higher measurements than the following vessel (R=1.27) and that this difference was greatest (R=1.48) when the Viking Storm was leading (or when the W. E. Ricker was following). In contrast, when the W. E. Ricker was leading (or when the Viking Storm was following), the ratio of the two vessels is approximately 1 (R=0.98). This suggests that the Viking Storm observed higher values than the W. E. Ricker when it was leading, but when it was following, it observed similar values. These results, along with the simple mean backscatter values, restated below, indicate that the source of the significant interaction term in the ANOVA are the higher values observed by the Viking Storm when it was leading.

	Leading	Following
Viking Storm	1,343 ($m^2/nm^{2)}$	345 ($m^2/nm^{2)}$
W. E. Ricker	415 ($m^2/nm^{2)}$	603 ($m^2/nm^{2)}$

It is important to note that although the trends support these results they are not strictly statistically significant. In fact, the ratio of the vessels (1.29) is approximately equal

to the ratio of the positions (1.27). This can be explained by the unbalanced sample whereby the Viking Storm led for 32 of the retained transects while the W. E. Ricker led for only 19.

The results raise concerns as to whether the two systems will provide similar estimates when ensonifying high fish densities, but the error may not lie with the adapted commercial sounder. Fish have been shown to respond to the noise stimuli of an approaching vessel by swimming radially away from the approaching vessel and downward (Misund 1997). In addition, the backscatter strength of a fish decreases as the tilt angle of the fish deviates from the tilt for maximum dorsal backscatter strength (MacLennan and Simmonds 1992). Thus, escape behaviour will not only reduce fish densities horizontally but also decrease the target strength of each individual fish (Misund 1997). Further, if the fish moved into the bottom 10 m of water, our editing process would exclude them from the backscatter measurements.

Sound ranging measurements on the W. E. Ricker indicated that it has a very large acoustic signature (Ken Cooke pers. comm.). If the W. E. Ricker elicited a stronger escape response, ahead of itself, than the Viking Storm, we would expect that the W. E. Ricker would record high Sal values less frequently, as we observed. We would also expect a larger leading/following effect when the Viking Storm led because it would have passed over the fish before the avoidance response. With the W. E. Ricker leading, both vessels would pass over the fish after the avoidance response. No sound range information was available for the Viking Storm.

Conversely, the results could have been caused by peculiarities of the Viking Storm system. It may function not to reduce its own density estimates but those of the following vessel, through a specific wake effect or eliciting a delayed escape response by the fish. Although we chose the following-distance to remove any apparent effects of the wake, we also cannot rule out the possibility that the wake of the leading vessel could have a differential impact on the trailing vessel. Nor can we rule out a delayed avoidance response. While we view these hypotheses as less likely than attributing the observations to the suggestion that the W. E. Ricker is a "noisy" vessel they highlight the difficulty in conducting definitive intercalibration studies.

APPLICATION FOR STOCK ASSESSMENT RESEARCH

While the project demonstrated that the backscatter estimates from the two systems were crudely comparable, it clearly revealed some of the practical issues that should be addressed prior to implementation of an acoustic biomass estimation program by commercial vessels. Firstly, if the commercial vessels tend to be small, they will find they are severely weather-limited or they will have to adopt a towed-body capability. Secondly, while simple calibration can be conducted on each system, rigorous intercalibration will be more problematic. Finally, the study demonstrated the need for trained and experienced operators for data editing, proofing, analysis, and interpretation. Any large-scale acoustic data collection program will require a considerable support infrastructure. We also suggest that since most individual commercial fishing operations have tightly optimized fishing activities, it will be difficult for the adapted vessel to divert from its fishing to conduct surveys without some financial incentive.

Adapted commercial sounders may prove more useful for studying fish distribution and behaviour for which relative density estimates are sufficient. This approach may be especially useful in conjunction with W. E. Ricker surveys. The less costly commercial acoustic platforms could be used to survey areas of lower density with only crude intercalibration established early in the cruise.

An additional objective of the study was to expose commercial fishers to the methodologies and limitations of acoustic biomass estimation. We found that the "hands-on" nature of the study helped clarify issues of near-bottom detection, species identification, and vessel and weather effects with respect to quantitative assessment. Fish density measurements and echogram interpretation are only the starting point for a comprehensive stock assessment, which requires several additional ingredients. In addition to adequate and timely area coverage, species discrimination and interpolation of density measurements to biomass, it requires meaningful and informed collaboration between fishers, scientists and managers.

SUMMARY AND CONCLUSIONS

We found that the installation, calibration, and operation of the portable acoustic system aboard a commercial vessel was feasible, efficient, and practical. However, data collection by this system was limited by stricter weather requirements than those of the research vessel. The difference in the acoustic recordings was primarily due to the research vessel's ram-mounted transducer versus the commercial vessel's hull-mounted transducer and not the vessel size or acoustic system. The present work was done under difficult but not a-typical weather conditions and thus suggests the importance of using a towed body or a ram-mounted transducer to guarantee high data quality.

We found that reasonably accurate acoustic fish density measurements are feasible from an "adapted" commercial sounder and that simple editing of the echogram for desired targets and to exclude noise can be done quite efficiently. However, the study also revealed the complexity of biases that are involved in these kinds of measurements and analysis, and emphasized the need for extreme care in interpreting acoustic data.

Although we have obtained reasonable results with an adapted system we would recommend the use of a "known" acoustic system that has an established record of accuracy, reliability and long-term stability. The importance of these properties is amplified by the fact that even careful bench and target calibrations only can provide spot-checks and by the high inherent variability in vessel intercalibration.

ACKNOWLEDGEMENTS

Fisheries and Oceans, Canada and the Canadian Groundfish Research and Conservation Society jointly funded this project. The cost of the charter was covered by an allocation of fish that was removed from the overall industry's quota. All individual quota holders, therefore, shared these costs. Fisheries and Oceans funding was provided

through the Stock assessment Division of Science Branch, Pacific Region, and the National Acoustic program. We would like to thank Travis Scheidl, Dr. Gary Melvin, and Alan Clay for their assistance with the HDPS system. The project also benefited from the participation and advice provided by Captain Kelly Anderson of the Viking Storm, and Captain Brian Dickens, who represented the Canadian Groundfish Research and Conservation Society. The report benefited from the careful and constructive review by George Cronkite.

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Table 1. Variables definition.

i = vessel (Viking Storm or W.E. Ricker)

j = position (leading or following)

k = transect

l = integration interval for each vessel

p = number of integration intervals in transect k

q = number of transects in the comparison

SaI_{ijkl} = individual integrated backscatter meaurements ($\mathrm{m}^2/\mathrm{nm}^2$)

$$\mathrm{SaT}_{ijk} = \frac{\sum_{l=1}^{p} \mathrm{SaI}_{ijkl}}{p}$$

Observations:

ANOVA model: $\log(\mathrm{SaI}_{ijkl}) = \mu + \alpha_i + \beta_j + \alpha_i\beta_j + \varepsilon_{ijkl}$

μ = the overall mean log-transformed SaI value for all transects and vessels

α_i = the effect of vessel

β_j = the effect of position

$\alpha_i\beta_j$ = the interaction effect between vessel i and position j

ε_{ijkl} = the error term, normally distibuted with a mean of 0 and a variance of σ^2

ANOVA:

Linear comparison:

$d_k = \log(\mathrm{SaT}_{1k}) - \log(\mathrm{SaT}_{2k})$ where 1 represents either a vessel or a position and 2 represents the other vess el or position

$$\bar{d} = \frac{\sum_{k=1}^{q} d_k}{q}$$

$$s_d = \frac{\sum_{k=1}^{q} (d_k - \bar{d})^2}{q-1}$$

t = value of the t - distributi on for the chosen level of error α, and the degrees of freedom $q-1$

$$\mathrm{R} = 10^{\bar{d}}$$

$$\text{confidence interval} = 10^{\bar{d} \pm t_{(\alpha, q-1)} s_d \sqrt{q}}$$

Table 2. Summary of micro-surveys completed by the W.E. Ricker and Viking Storm during the widow rockfish hydroacoustic survey, Jan. 15 – Feb. 8, 1999. Start time is the Pacific Standard Time (PST) at which the micro-survey was started and is taken from the W.E. Ricker bridge log. For each micro-survey the total number (N), minimum (min), and maximum (max) Sal as well as the overall micro-survey mean Sa values are shown. For the paired micro-surveys, the comparable transects are shown and the leading vessel is in bold. For micro-survey I03, the Viking Storm led the first transect and the W.E. Ricker led the second transect.

Micro-survey	Date (dd-mm-yy)	Comparable transects	Start time (PST)	W. E. Ricker Sa values (m^2/nm^2)				Viking Storm Sa values (m^2/nm^2)			
				N Sal	min Sal	max Sal	mean	N Sal	min Sal	max Sal	mean
A02	23-01-99	5-11	20:05	100	17	23,653	830	71	0	63,752	1942
A03	24-01-99	8-10	01:23	53	56	1.538	394	30	9	1,058	223
A04	24-01-99	3-11	06:32	192	0	7,169	624	124	0	110,788	2,389
A05	24-01-99	1,3,5,7,9	10:47	109	0	25,684	750	73	0	8,026	479
A06	24-01-99	1,3,5	17:19	88	23	3,040	669	65	6	7,665	926
A08	25-01-99	3,5,7,9-11	05:08	117	0	40,542	1,187	83	1	76,646	1,641
A09	25-01-99	3-6	09:34	144	0	23,062	561	101	0	7,153	499
A10	28-01-99	--	12:53	240	0	14,974	791	--	--	--	--
A11	28-01-99	--	18:44	233	19	18,388	992	--	--	--	--
A12	29-01-99	--	00:12	236	0	10,536	791	--	--	--	--
A13	29-01-99	--	06:55	131	1	10,457	868	--	--	--	--
E01	29-01-99	--	13:00	489	0	76,302	3,757	--	--	--	--
I01	27-01-99	1-2	15:53	39	0	518	124	23	94	609	333
I02	27-01-99	1-2	16:49	61	43	437	151	42	57	943	276
I03	27-01-99	1-2	17:51	62	63	303	140	43	86	518	186
I04	04-02-99	1-2	06:55	60	18	263	83	43	19	260	103
I05	04-02-99	1-2	08:06	61	23	355	108	44	25	473	187
I06	04-02-99	1-2	09:14	61	16	580	154	44	4	860	198
I07	04-02-99	1-2	10:25	62	15	748	133	44	41	1,010	195

Table 3. Results of the ANOVA Type III sum of squares test for significance of the vessel, position, and the interaction of vessel and position on the log-transformed Sal values. The model is shown for all Sal values (A) and for all Sal values less than 50,000 (B).

A) All Sal values Factor	df	SS	MS	F-value	p-value
vessel	1	1.03	1.03	2.05	0.15
position	1	0.25	0.25	0.50	0.48
vessel*position	1	42.91	42.91	85.23	<0.001
Residual	1984	998.97	0.50		
Total	1987	1043.17			

B) Sal < 50,000 Factor	df	SS	MS	F-value	p-value
vessel	1	0.71	0.71	1.45	0.23
position	1	0.11	0.11	0.22	0.64
vessel*position	1	40.65	40.64	82.27	<0.001
Residual	1981	978.71	0.49		
Total	1984	1020.18			

Table 4. Ratio of Logs (Kieser *et al.* 1987) to compare vessels, positions, and positions when each vessel is following. Ratios are calculated from the SaT values for all Sal values (A), and for all Sal values less than 50,000 (B). Upper and lower 95% confidence limits (CL) are shown as well as the number of SaT pairs used in the model.

Comparison A) All Sal values	lower 95% CL	ratio	upper 95% CL	N
Viking Storm to W.E. Ricker	0.97	1.29	1.71	51
leading to following	0.96	1.27	1.69	51
leading to following when VS following	0.70	0.98	1.39	19
leading to following when WER following	0.99	1.48	2.23	32
B) Sal < 50,000				
Viking Storm to W.E. Ricker	0.92	1.20	1.55	51
leading to following	0.91	1.18	1.53	51
leading to following when VS following	0.70	0.98	1.39	19
leading to following when WER following	0.91	1.32	1.90	32

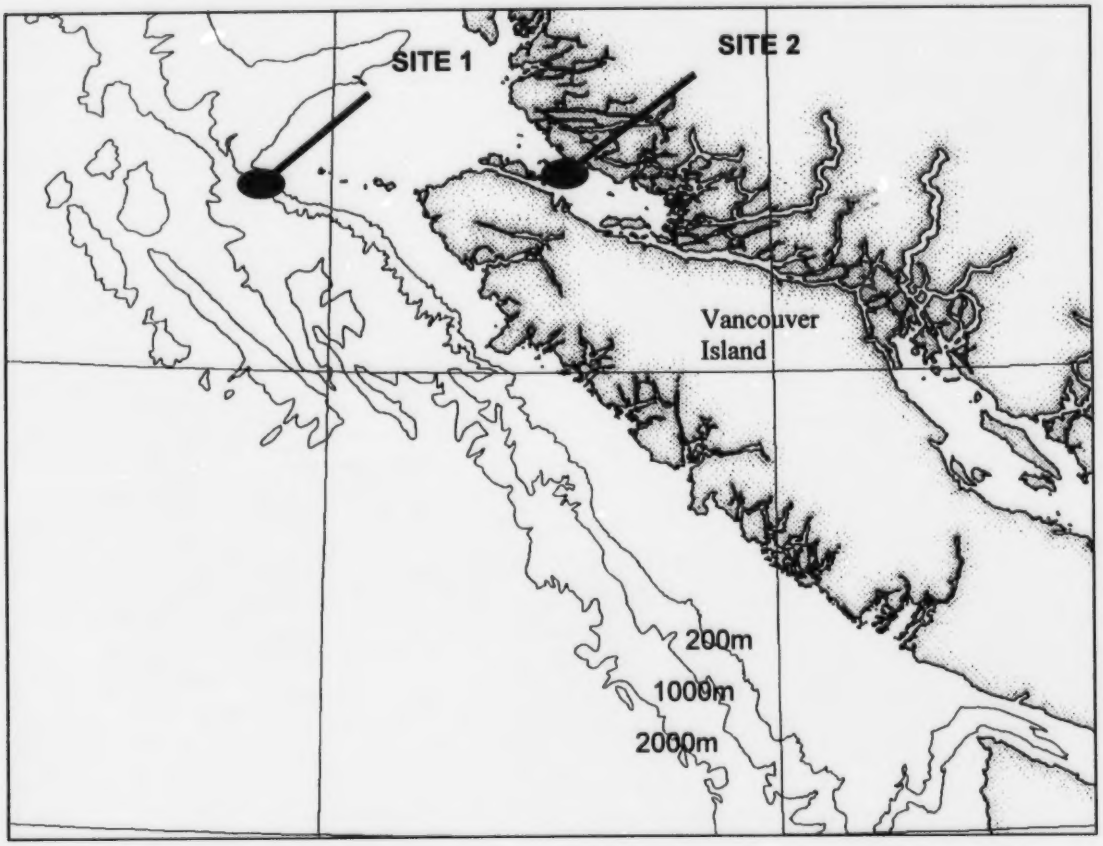


Fig. 1. Location of the Triangle Island (Site 1) and Goletas Channel (Site 2) study sites used in the intercalibration study.

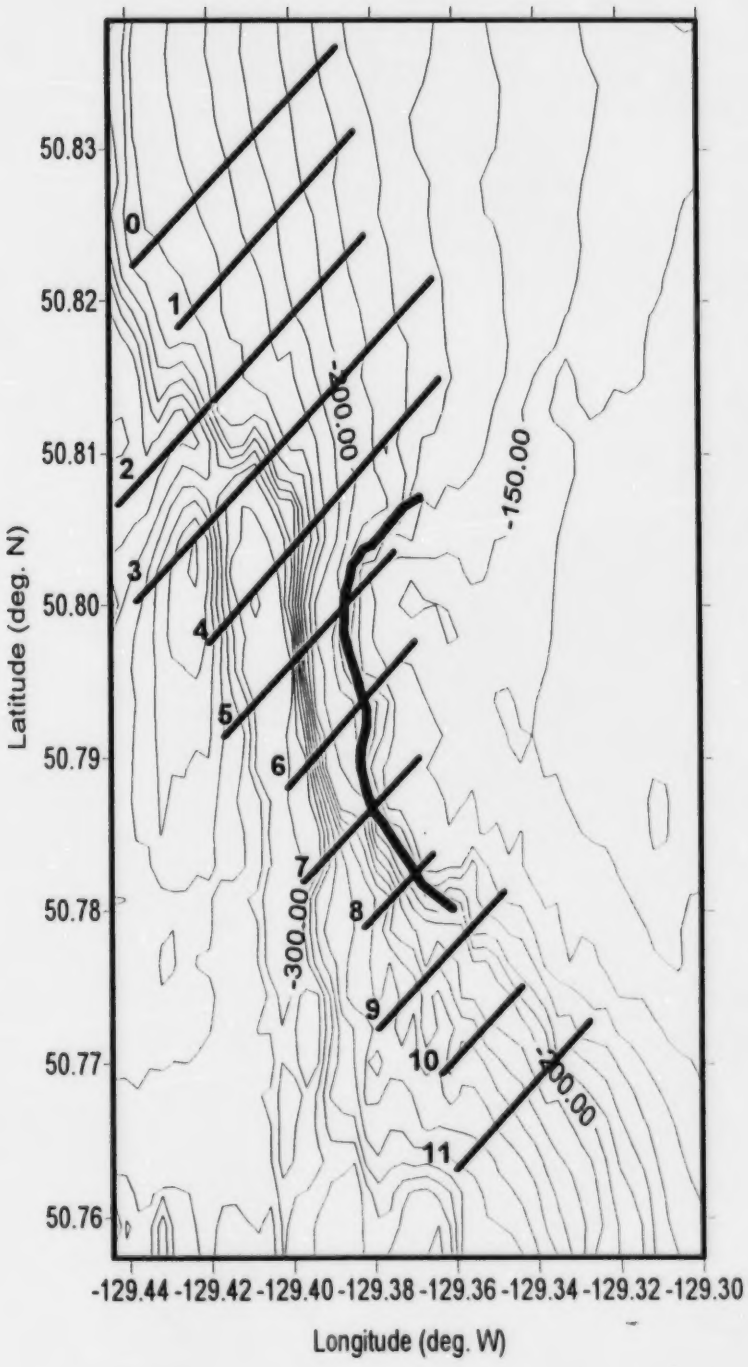


Fig. 2. Transect design at the Triangle Island study site with the A series transects shown with a straight black line and the E series transect shown with a curved grey line. Even numbered transects were surveyed while travelling south-west while odd numbered transects were surveyed towards the north-east. Contour depths are in meters.

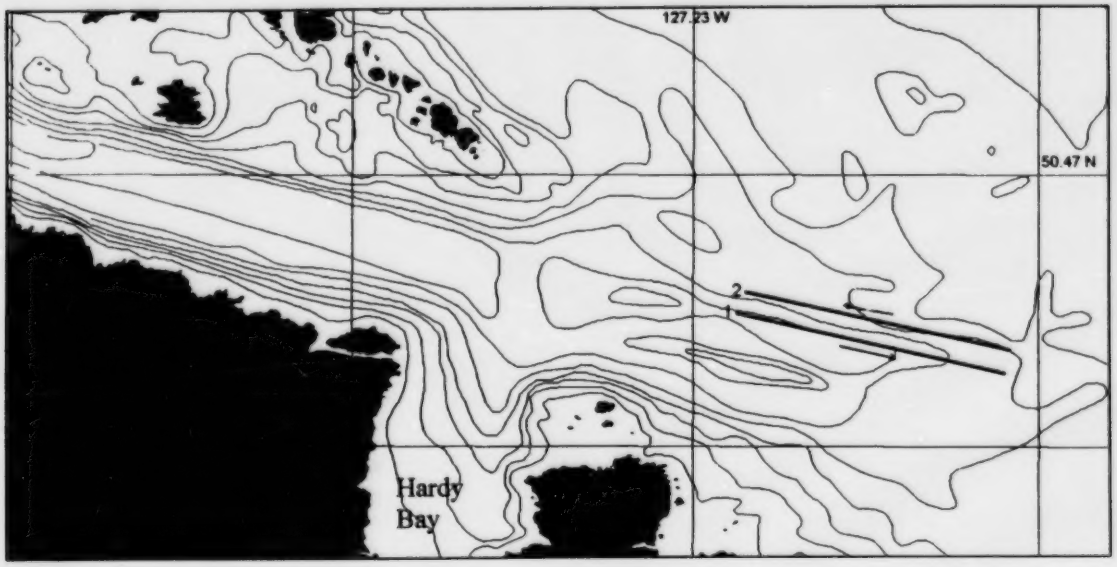


Fig. 3. Transect design at the Goletas Channel study site with arrows indicating the direction surveyed. Contours are shown at 50m intervals.

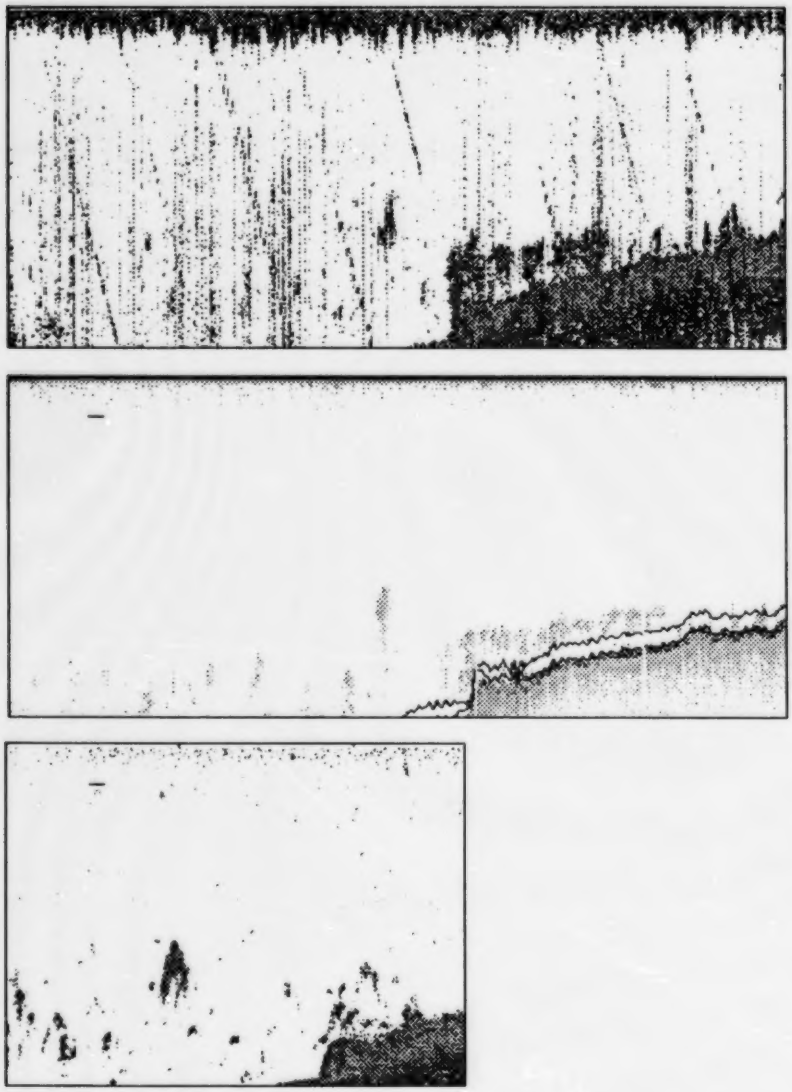


Fig. 4. Example echograms from the Viking Storm (A and C) and the W. E. Ricker (B) hydroacoustic systems showing from 0 to 200 m depth. Echograms A and B are from transect A0911 and show the different echogram qualities associated with the two hydroacoustic systems during poor weather. The former echogram pair was assigned a poor quality. A good quality echogram from the Viking Storm for the same transect but micro-survey A04 is shown in Panel C. Note the following: (1) that interference from Viking Storm's 50 kHz echosounder is indicated as slanted lines in Panel A; (2) that transect A0911 (Panels A and B) was longer than A0411 (Panel C); (3) the 10-m bottom buffer shown in Panel B.

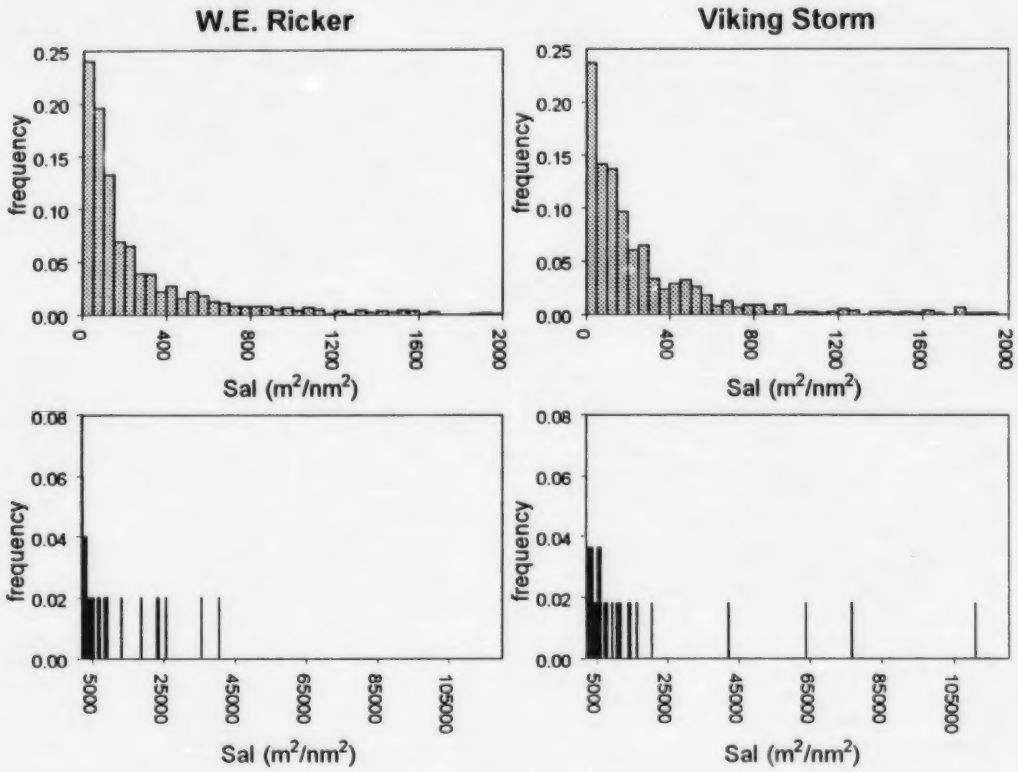


Fig. 5. Frequency distributions of the Sal values for the W.E. Ricker and the Viking Storm. The upper histograms show the values between 0 and 2000 m^2/nm^2 while the lower histograms show the values between 2,000 and 120,000 m^2/nm^2.

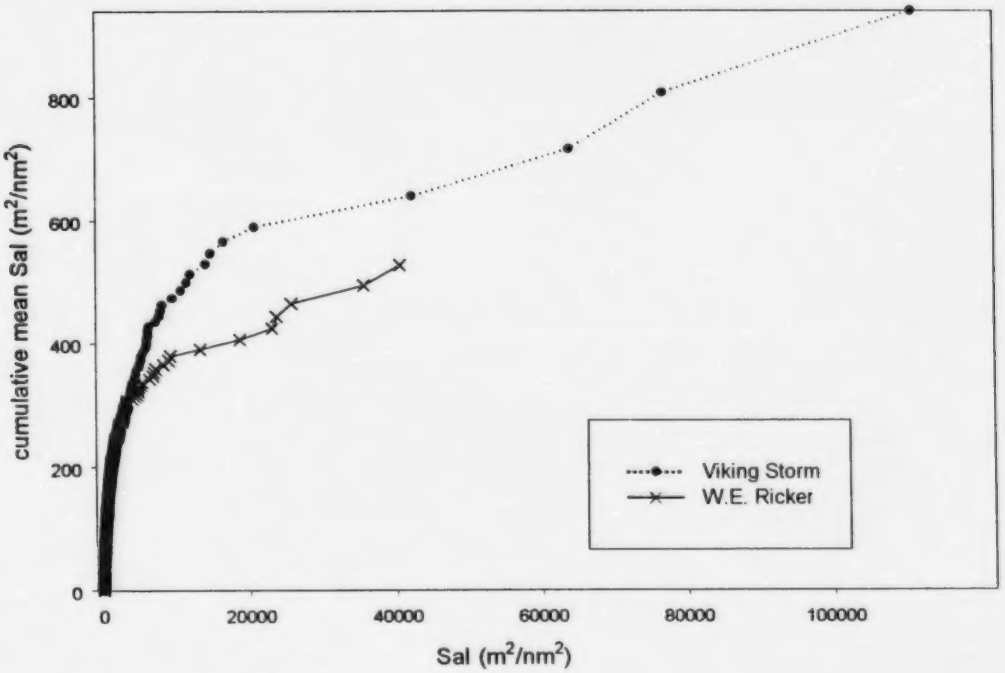


Fig. 6. Plot of the cumulative mean of the Sal values versus the ordered Sal values for the W.E. Ricker (N=1209, mean = 526) and the Viking Storm (N=830, mean = 940). The cumulative mean Sa at any point along the horizontal axis is calculated from all the Sa values less than or equal to the value at that point.

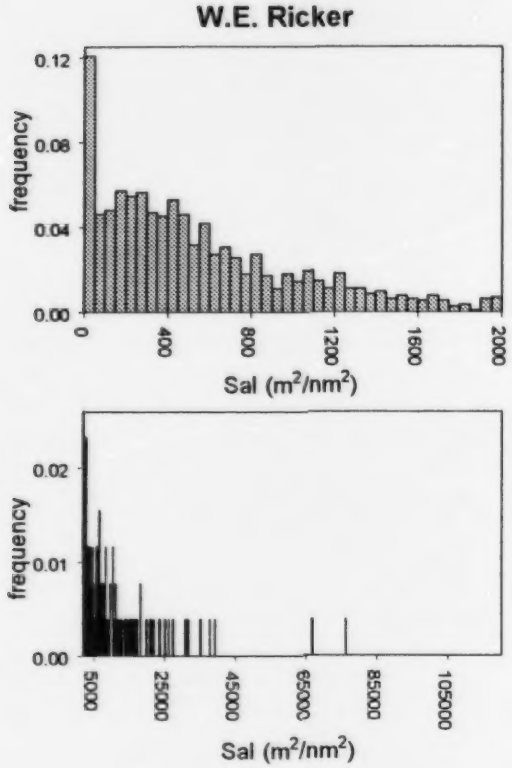


Fig. 7. Distributions of the Sal values for the W.E. Ricker from the unpaired transects conducted at the Triangle island study site (micro-surveys A10 – A13, E01, and the return legs of micro-surveys A03 and A07). The upper histogram shows the values between 0 and 2,000 m^2/nm^2 while the lower histogram shows the values between 2,000 and 120,000 m^2/nm^2.

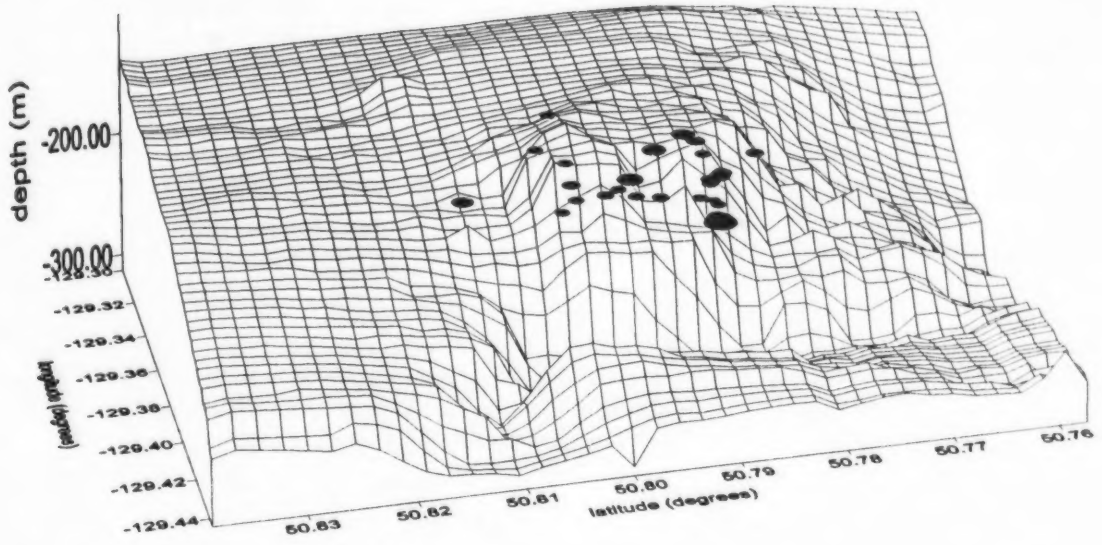


Fig. 8. Location of Sal values greater than 20,000 m^2/nm^2 at the Triangle Island study site for both the W.E. Ricker (red), and the Viking Storm (black). The area of the disk is proportional to the Sa value.

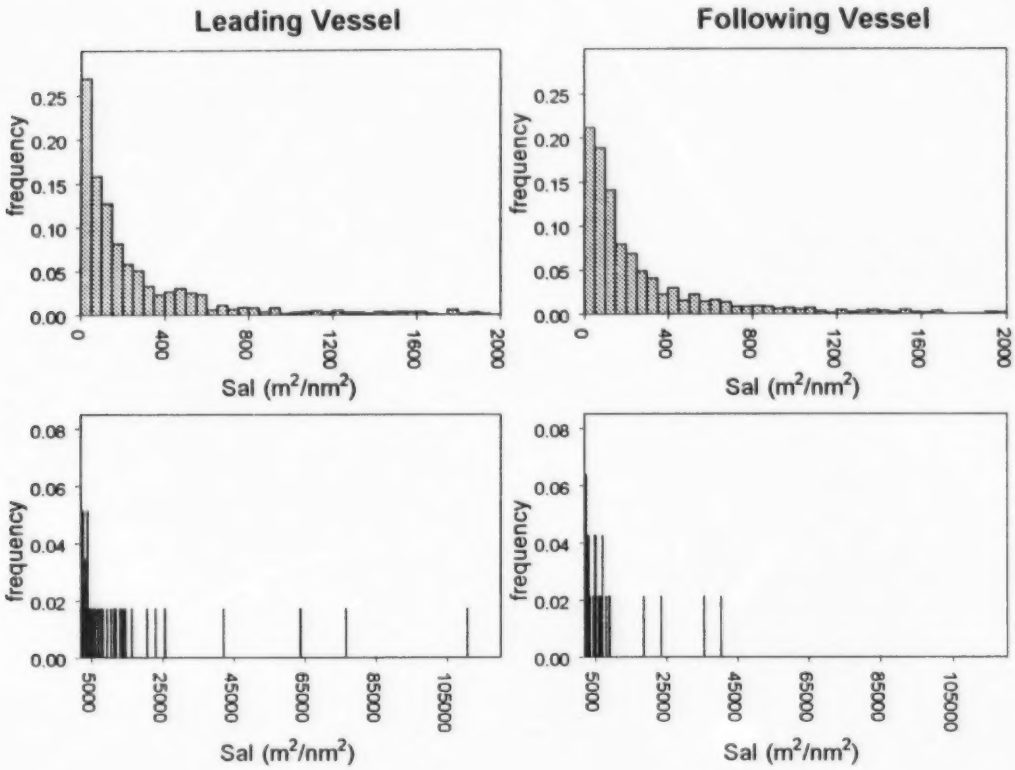


Fig. 9. Frequency distributions of the Sal values for the leading and following vessels. The upper histograms show the values between 0 and 2,000 m^2/nm^2 while the lower histograms show the values between 2,000 and 120,000 m^2/nm^2.

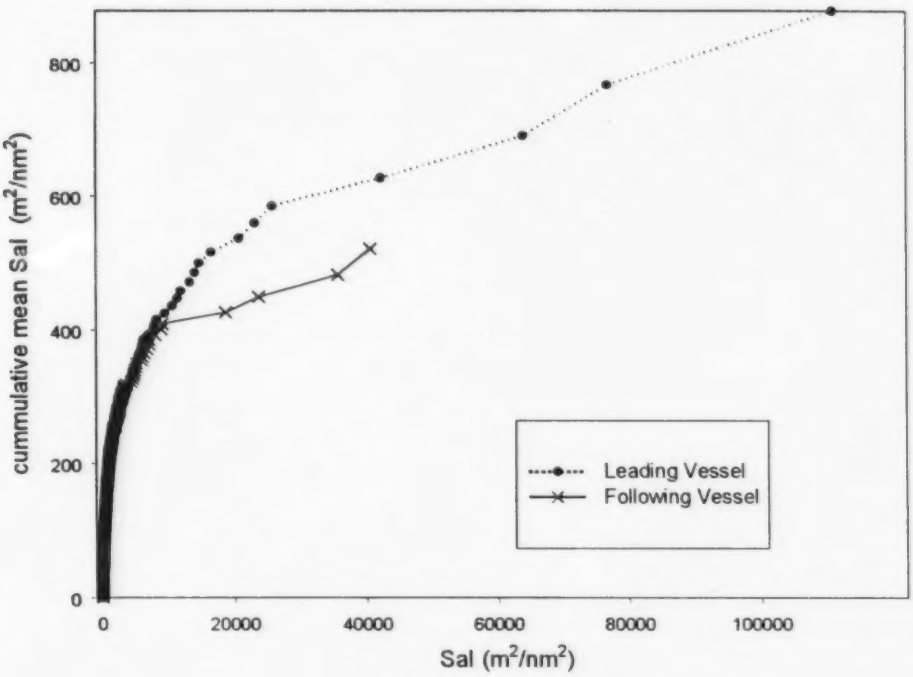


Fig. 10. Plot of the cumulative mean of the Sal values versus the ordered Sal values for the leading (N=991, mean = 878) and following (N=1048, mean = 521) vessels. The cumulative mean Sa at any point along the horizontal axis is calculated from all the Sa values less than or equal to the value at that point.

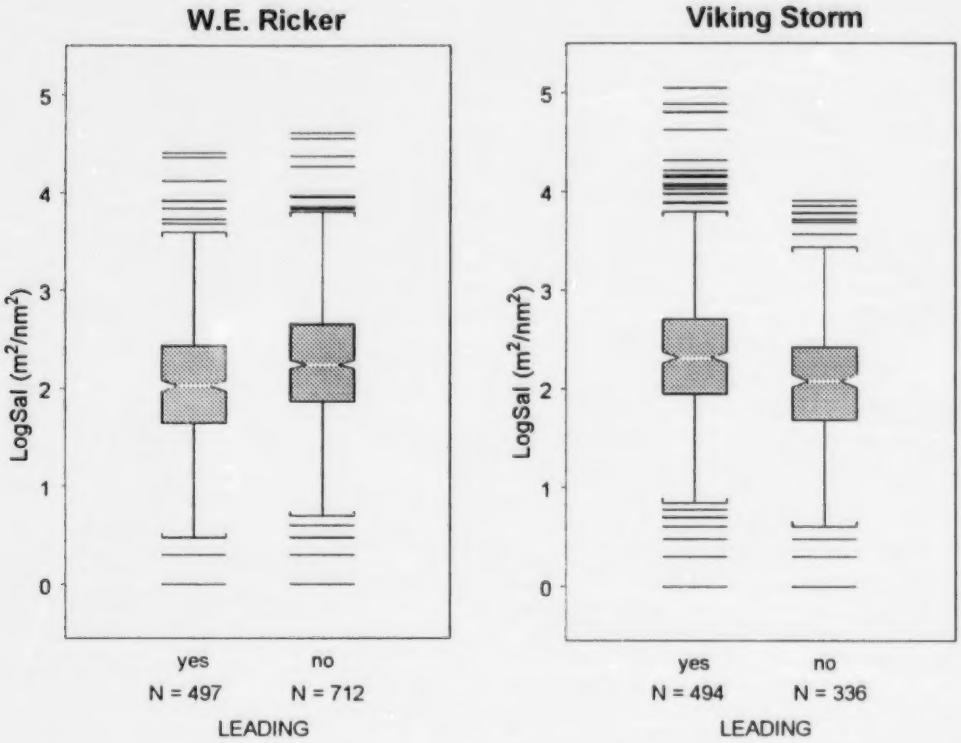


Fig. 11. Box and whisker plots of the log-transformed Sal values for the Viking Storm and the W.E. Ricker showing medians (white bars), and its 95% confidence limits (notches), first and third quartiles (boxes), 1.5* the interquartile range (whiskers), and outliers beyond the whiskers (solid bars).

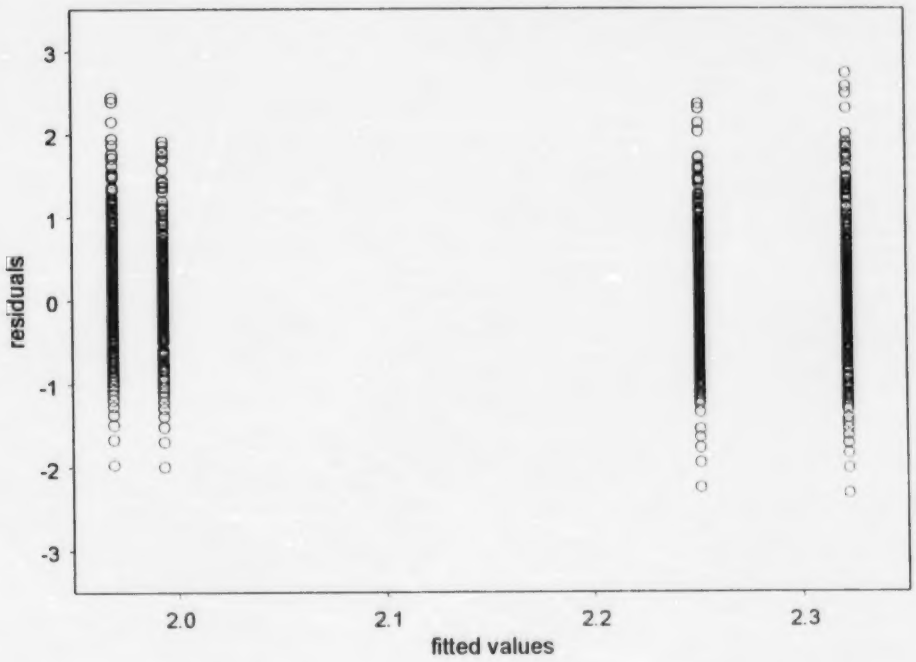


Fig. 12. Plot of the ANOVA model residuals versus fits.

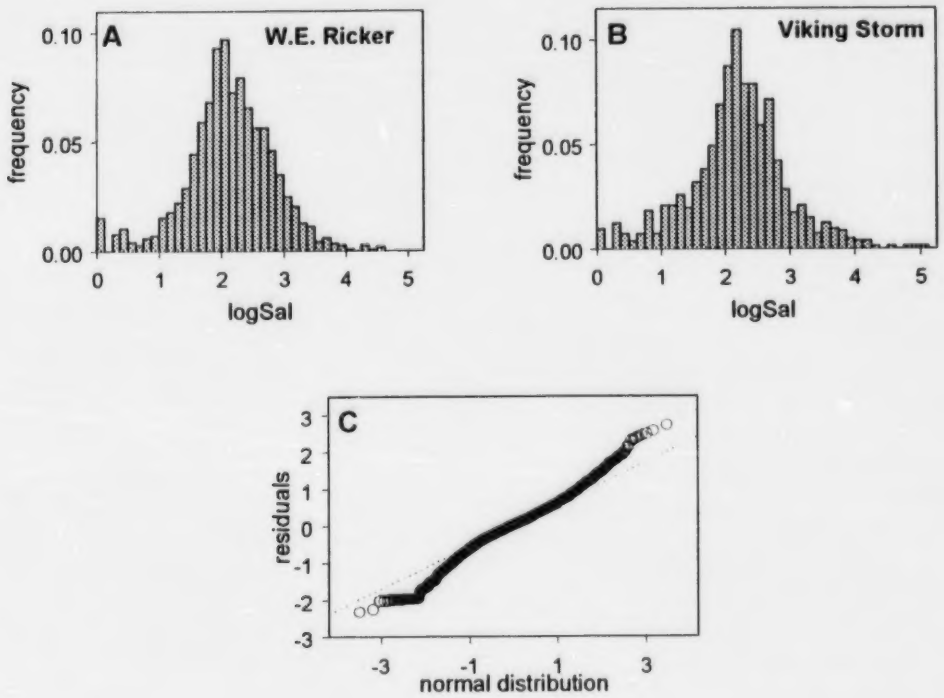


Fig. 13. Verifications of the ANOVA assumption of normally distributed data showing the frequency distributions of the Sal values for the W.E. Ricker (A) and the Viking Storm (B), and the ANOVA model residuals versus normal quantiles plot (C).

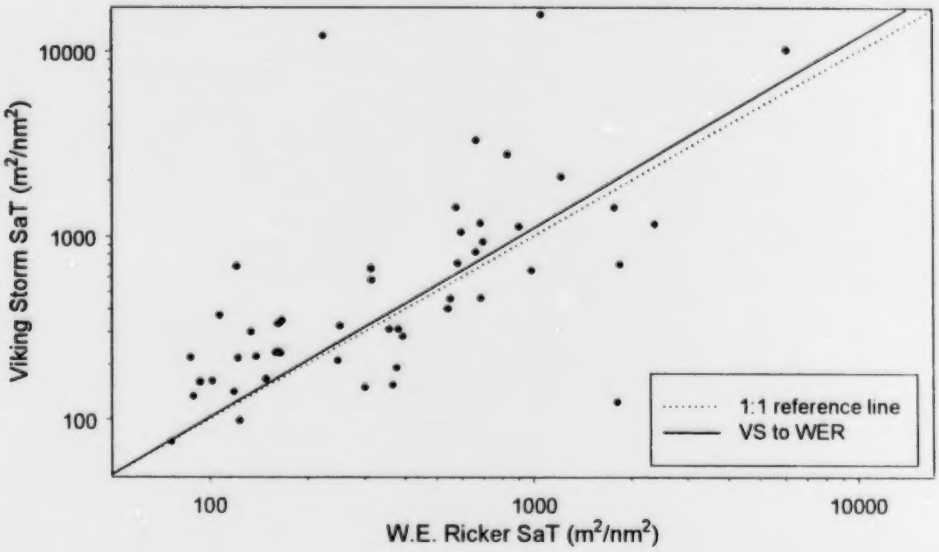


Fig. 14. Logarithmic scaled plot of the Viking Storm SaT versus the W.E. Ricker SaT values. A 1:1 reference line and a line representing the Ratio of Logs ratio of the Viking Storm to the W.E. Ricker with an intercept of zero (VS to WER) are shown.

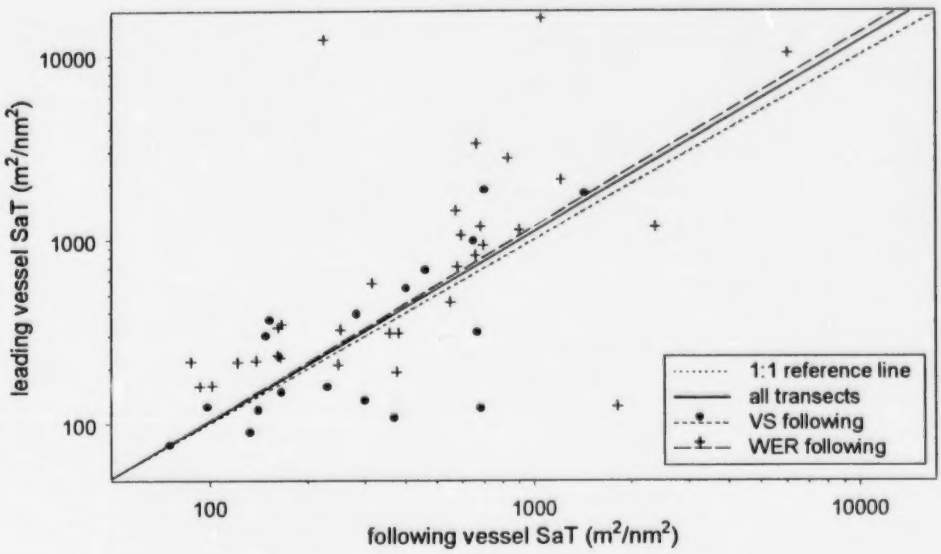


Fig. 15. Logarithmic scaled plot of the leading vessel SaT versus the following vessel SaT. A 1:1 reference line is shown, as are lines representing the Ratio of Logs ratios for all transects, those where the Viking Storm was following, and those where the W.E. Ricker was following. All lines representing ratios have intercepts of zero. Note that the 1:1 reference line and the ratio line for the transects where the Viking Storm was following coincide.

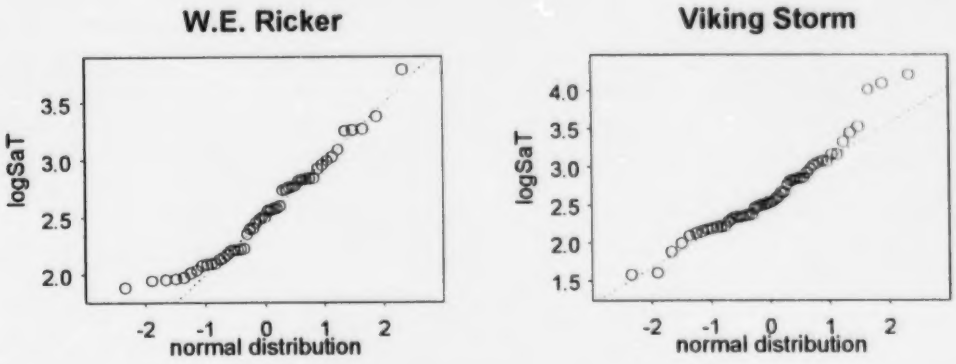


Fig. 16. Plot of the log-transformed SaT values versus the normal quantiles for Viking Storm (left) and the W.E. Ricker (right).

Appendix Table 1. Summary of micro-surveys and transects. Start time (PST) taken from the W.E. Ricker log except when the W.E. Ricker did not complete the transect when it is taken from the Viking Storm log. For the paired transects, the leading vessel is in bold. The quality (Q; good =g, poor =p) of the Viking Storm echogram is also shown.

Micro-survey	Tr	Date (dd-mm-yy)	Start time (PST)	W.E. Ricker Sa values (m^2/nm^2)				Viking Storm Sa values (m^2/nm^2)				
				N Sal	Min Sal	max Sal	SaT	N Sal	Min Sal	max Sal	SaT	Q
A01	01	22-01-99	05:33	19	46	466	224	16	13	248	92	p
	02	22-01-99	05:58	26	5	580	139	21	9	652	140	p
	03	22-01-99	06:32	31	0	1106	302	29	1	1134	219	p
	04	22-01-99	07:13	25	0	1887	525	21	1	3270	625	p
	05	22-01-99	07:48	19	0	13008	1726	20	0	38414	3559	p
	06	22-01-99	08:14	14	51	9958	1675	14	3	2160	942	p
	07	22-01-99	08:43	13	104	27410	4658	12	49	13016	2178	p
	08	22-01-99	09:07	8	9	13758	5171	8	130	8213	2746	p
	09	22-01-99	09:28	14	255	5040	967	13	164	1839	900	p
	10	22-01-99	09:49	12	0	3058	321	9	65	1215	376	p
	11	22-01-99	10:10	15	9	1345	382	13	27	6524	1039	p
A02	01	23-01-99	20:05	23	7	1442	381	16	52	2211	499	p
	02	23-01-99	20:33	27	18	2037	378	20	0	3585	428	p
	03	23-01-99	21:26	36	17	3785	455	–	–	–	–	
	04	23-01-99	21:47	30	13	4334	613	19	0	56819	3883	p
	05	23-01-99	22:21	19	17	23653	1817	13	7	652	124	g
	06	23-01-99	22:48	11	17	18659	2376	11	19	7843	1168	g
	07	23-01-99	23:10	18	50	1027	224	9	23	63752	12197	g
	08	23-01-99	23:32	15	29	2206	552	10	0	1881	456	g
	09	23-01-99	23:54	14	28	689	252	10	8	1756	324	g
	10	24-01-99	00:15	9	83	263	167	7	20	1756	346	g
	11	24-01-99	00:32	14	102	1071	357	11	42	732	310	g
A03	01	24-01-99	01:23	25	0	77	35	16	2	119	39	p
	02	24-01-99	01:51	30	0	176	34	–	–	–	–	
	03	24-01-99	02:23	27	0	185	28	–	–	–	–	
	04	24-01-99	02:54	24	0	129	40	–	–	–	–	
	05	24-01-99	03:22	19	0	164	52	–	–	–	–	
	06	24-01-99	03:47	14	10	5162	693	–	–	–	–	
	07	24-01-99	04:08	12	61	20635	1955	–	–	–	–	
	08	24-01-99	04:28	9	57	1538	685	7	9	1058	462	g
	09	24-01-99	04:43	21	56	631	300	10	75	260	148	g
	10	24-01-99	05:07	23	62	949	366	13	10	451	153	g
	11	24-01-99	05:34	15	61	2008	468	–	–	–	–	
	99	24-01-99	05:51	48	83	9353	849	–	–	–	–	
A04	03	24-01-99	06:32	33	16	1454	280	20	2	384	37	g
	04	24-01-99	07:06	26	10	1060	248	17	2	1160	209	g
	05	24-01-99	07:35	37	12	7169	1218	23	16	5950	2102	g
	06	24-01-99	08:15	32	0	6326	831	21	37	20630	2756	g
	07	24-01-99	08:47	12	4	6787	1058	9	149	110788	15882	g
	08	24-01-99	09:06	8	16	2191	665	6	254	16387	3305	g
	09	24-01-99	09:22	14	0	1218	315	10	0	2783	576	g

Appendix Table 1. (cont'd)

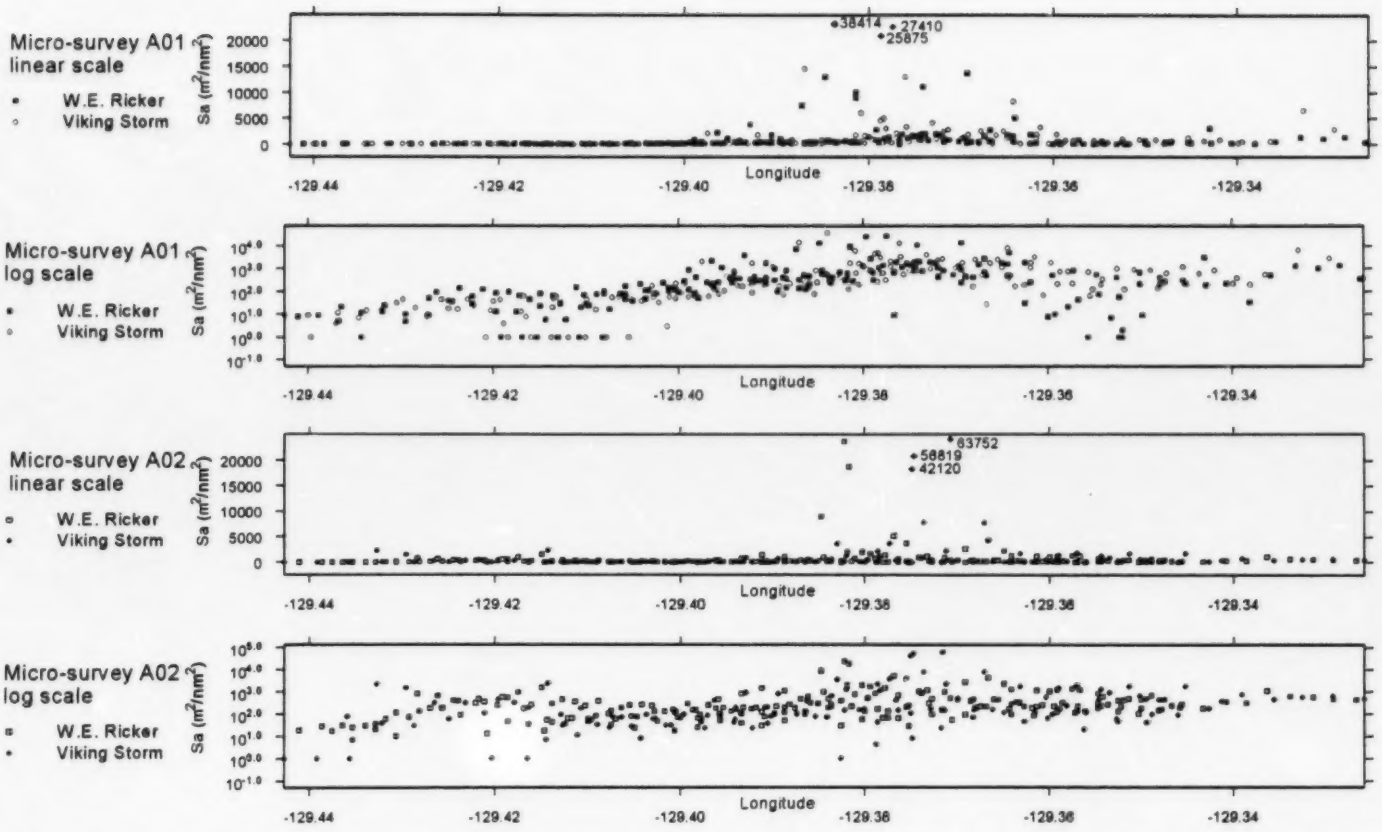
Micro-survey	Tr	Date (dd-mm-yy)	Start time (PST)	W.E. Ricker Sal values (m^2/nm^2) N	Min	max	SaT	Viking Storm Sal values (m^2/nm^2) N	Min	max	SaT	Q
	10	24-01-99	09:42	15	10	331	88	7	20	431	217	g
	11	24-01-99	10:00	15	0	2880	574	11	0	10580	1429	g
A05	01	24-01-99	10:47	24	0	544	124	16	1	320	98	g
	02	24-01-99	10:15	27	0	434	99	19	0	260	59	p
	03	24-01-99	11:48	32	0	1468	91	23	0	211	40	g
	04	24-01-99	12:24	25	0	797	209	19	12	965	188	p
	05	24-01-99	12:37	20	0	25684	1855	13	0	5950	701	g
	06	24-01-99	13:24	14	0	1045	229	11	2	1839	562	p
	07	24-01-99	13:46	12	0	925	121	9	0	5182	683	g
	08	24-01-99	14:07	12	2	6777	1106	14	4	860	230	p
	09	24-01-99	14:36	21	1	13187	1777	12	0	8026	1436	g
	10	24-01-99	14:59	21	5	6311	1289	14	22	4513	962	p
	11	24-01-99	15:28	21	12	4432	647	14	4	1243	375	p
A06	00	24-01-99	17:19	25	14	1960	481	17	61	821	347	p
	01	24-01-99	17:46	26	75	2212	596	18	92	3424	1051	g
	02	24-01-99	18:16	30	11	3135	592	19	0	2016	595	p
	03	24-01-99	18:50	39	23	1650	580	28	6	7665	710	g
	04	24-01-99	19:32	33	79	1155	490	23	61	1010	390	p
	05	24-01-99	20:11	23	86	3040	435	19	17	5182	1127	g
	06	24-01-99	20:42	21	96	8737	2436	13	23	7665	2398	p
	07	24-01-99	21:08	14	118	16728	2364	10	113	36685	4757	p
	08	24-01-99	21:26	8	459	2499	1468	6	206	2783	1590	p
	09	24-01-99	21:41	15	228	1289	711	10	77	1272	617	p
	10	24-01-99	22:01	10	281	1403	690	7	108	1639	565	p
	11	24-01-99	22:17	14	91	1230	470	11	45	1215	322	p
A07	01	24-01-99	23:08	26	258	1331	752	17	20	766	375	p
	02	24-01-99	23:36	33	25	1144	450	21	40	1332	299	p
	03	25-01-99	00:12	39	20	2562	620	27	27	3051	591	p
	04	25-01-99	00:56	34	35	1855	533	25	53	1058	379	p
	05	25-01-99	01:36	24	21	771	205	16	38	1058	193	p
	06	25-01-99	02:05	22	54	7170	926	14	16	5682	619	p
	07	25-01-99	02:31	15	102	6849	831	9	34	7320	1083	p
	08	25-01-99	02:50	14	19	5680	725	7	8	384	222	p
	09	25-01-99	03:11	21	96	1057	385	13	0	312	86	p
	10	25-01-99	03:38	15	74	1191	322	13	16	298	121	p
	11	25-01-99	04:03	21	49	1187	375	14	1	484	116	p
	99	25-01-99	04:27	49	1	66793	1610					
A08	03	25-01-99	05:08	39	1	1158	376	25	1	803	190	g
	04	25-01-99	05:50	34	11	1796	366	23	16	699	202	p
	05	25-01-99	00:25	24	12	9150	698	15	6	11337	930	g
	06	25-01-99	06:52	19	50	11099	1461	13	29	5182	648	p
	07	25-01-99	07:20	14	85	40542	6065	9	42	76646	10226	g
	08	25-01-99	07:38	9	88	2809	802	6	31	2111	757	p
	09	25-01-99	07:54	14	2	2852	683	10	24	5814	1174	g
	10	25-01-99	08:15	11	288	2238	660	7	506	1160	821	g
	11	25-01-99	08:33	15	0	1044	381	11	5	668	310	g

Appendix Table 1. (cont'd)

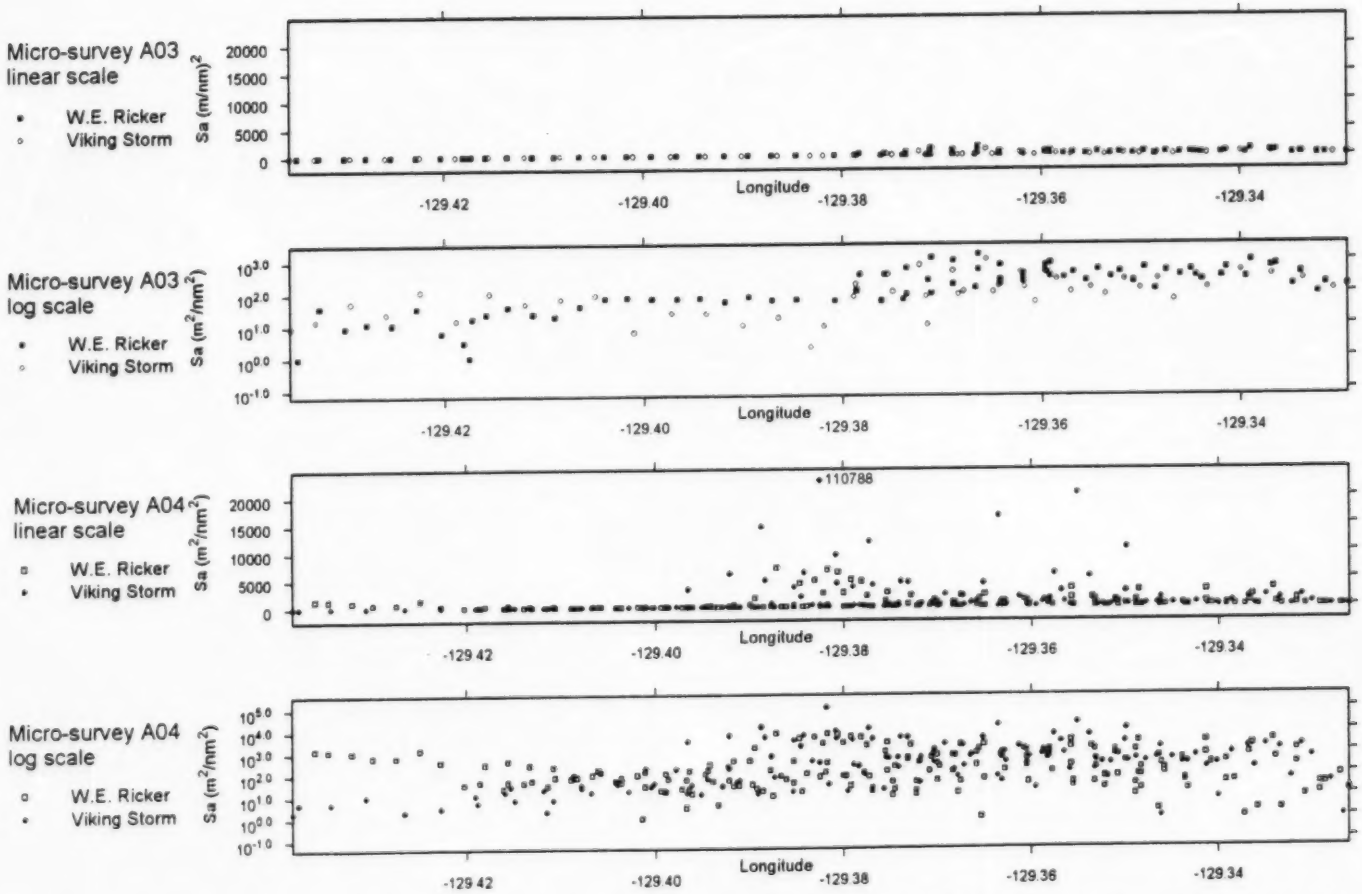
Micro-survey	Tr	Date (dd-mm-yy)	Start time (PST)	W.E. Ricker Sal values (m^2/nm^2)				Viking Storm Sal values (m^2/nm^2)				
				N	Min	max	SaT	N	Min	max	SaT	Q
A09	03	25-01-99	09:34	40	0	3917	394	27	2	2262	282	g
	04	25-01-99	10:05	34	1	1584	314	24	0	71535	667	g
	05	25-01-99	10:44	37	0	23062	985	27	1	3669	650	g
	06	25-01-99	11:35	33	0	5376	543	23	0	4836	401	g
	07	25-01-99	12:05	13	0	4527	555	9	4	24238	3848	p
	08	25-01-99	12:23	19	0	2030	359	9	48	880	242	p
	09	25-01-99	12:48	22	0	3585	691	16	2	1565	357	p
	10	25-01-99	13:14	16	6	1415	432	10	77	462	306	p
	11	25-01-99	13:36	27	0	914	245	20	7	484	164	p
A10	01	28-01-99	12:53	23	14	2480	541	–	–	–	–	
	02	28-01-99	13:20	37	0	1093	382	–	–	–	–	
	03	28-01-99	13:37	36	0	1512	210	–	–	–	–	
	04	28-01-99	14:38	26	0	1094	230	–	–	–	–	
	05	28-01-99	15:08	25	1	6632	885	–	–	–	–	
	06	28-01-99	15:37	22	0	2467	577	–	–	–	–	
	07	28-01-99	16:03	13	0	13989	2764	–	–	–	–	
	08	28-01-99	16:19	10	1	14974	3587	–	–	–	–	
	09	28-01-99	16:34	17	0	8041	1204	–	–	–	–	
	10	28-01-99	16:53	15	9	7812	1095	–	–	–	–	
	11	28-01-99	17:11	16	9	2159	386	–	–	–	–	
A11	01	28-01-99	18:44	21	146	669	304	–	–	–	–	
	02	28-01-99	19:11	30	46	575	240	–	–	–	–	
	03	28-01-99		40	19	3185	791	–	–	–	–	
	04	28-01-99		28	36	1472	614	–	–	–	–	
	05	28-01-99	20:50	22	41	18388	1414	–	–	–	–	
	06	28-01-99	21:17	18	117	5361	1178	–	–	–	–	
	07	28-01-99	21:42	17	123	13042	3712	–	–	–	–	
	08	28-01-99	22:02	14	201	6699	1930	–	–	–	–	
	09	28-01-99	22:21	18	231	1200	546	–	–	–	–	
	10	28-01-99	22:43	10	438	1110	703	–	–	–	–	
	11	28-01-99	2:58	15	231	1195	625	–	–	–	–	
A12	01	29-01-99	00:12	23	19	609	291	–	–	–	–	
	02	29-01-99	00:38	28	0	421	191	–	–	–	–	
	03	29-01-99	01:08	34	5	1041	330	–	–	–	–	
	04	29-01-99	01:46	28	28	776	386	–	–	–	–	
	05	29-01-99	02:20	26	54	8668	1282	–	–	–	–	
	06	29-01-99	02:47	21	192	5882	1623	–	–	–	–	
	07	29-01-99	03:13	12	267	10536	2742	–	–	–	–	
	08	29-01-99	03:29	10	478	2243	1542	–	–	–	–	
	09	29-01-99	03:43	17	151	1187	752	–	–	–	–	
	10	29-01-99	04:04	13	277	1143	680	–	–	–	–	
	11	29-01-99	04:21	24	78	4491	639	–	–	–	–	
A13	04	29-01-99	06:55	27	22	1304	478	–	–	–	–	
	05	29-01-99	07:26	19	23	4415	831	–	–	–	–	
	06	29-01-99	07:50	15	176	10457	2287	–	–	–	–	
	07	29-01-99	08:09	19	1	2623	543	–	–	–	–	
	08	29-01-99	08:32	12	43	3939	1192	–	–	–	–	
	09	29-01-99	08:49	13	166	1511	750	–	–	–	–	
	10	29-01-99	09:08	12	246	1515	745	–	–	–	–	
	11	29-01-99	09:26	14	131	1183	526	–	–	–	–	

Appendix Table 1. (cont'd)

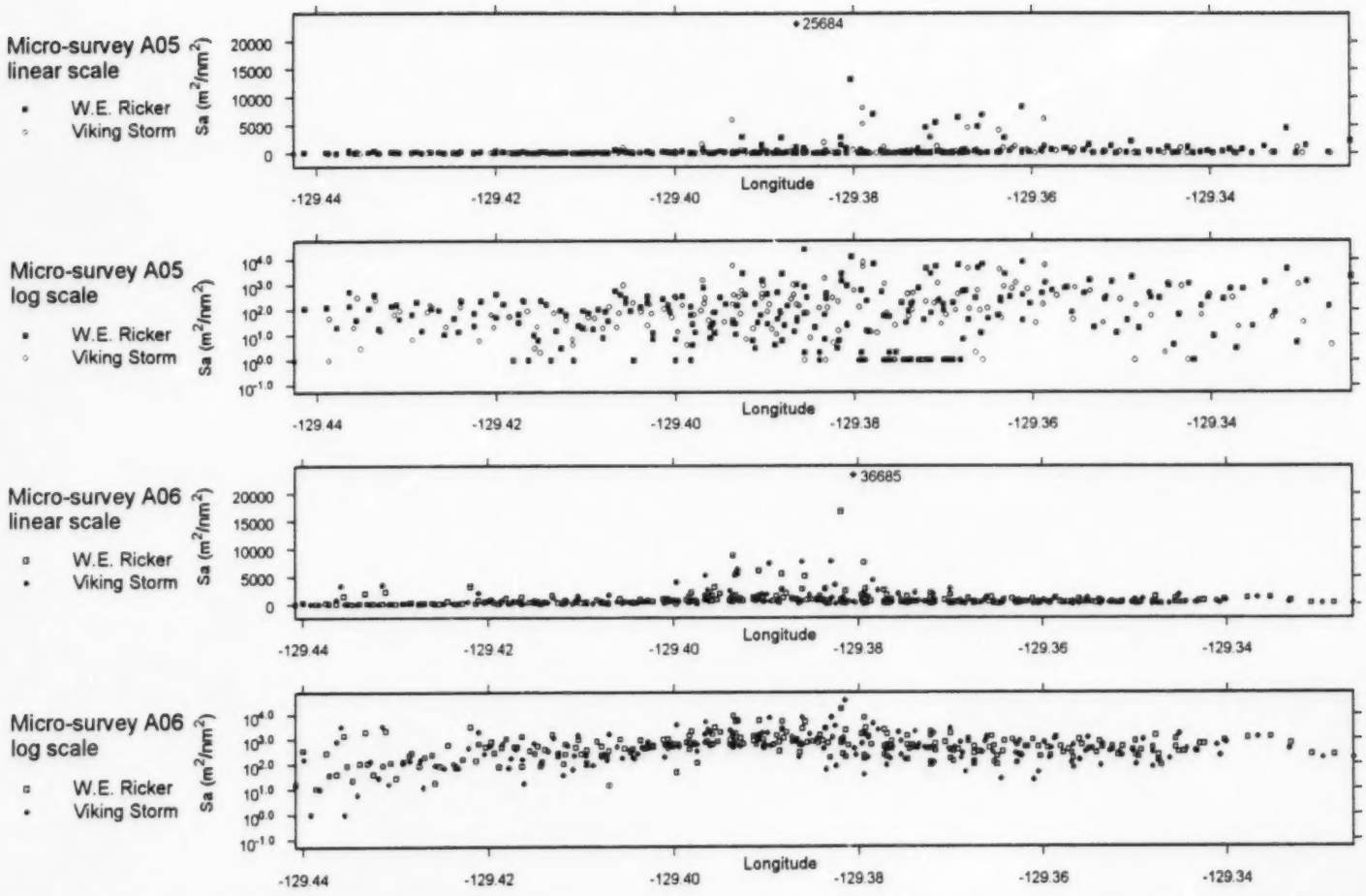
Micro-survey	Tr	Date (dd-mm-yy)	Start time (PST)	W.E. Ricker Sal values (m^2/nm^2) N	Min	max	SaT	Viking Storm Sal values (m^2/nm^2) N	Min	max	SaT	Q
E01	00	29-01-99		45	0	14059	1230	–	–	–	–	
	01	29-01-99	14:06	38	36	15424	1563	–	–	–	–	
	02	29-01-99	15:52	28	47	30815	4155	–	–	–	–	
	03	29-01-99	16:37	28	91	37868	3562	–	–	–	–	
	04	29-01-99	17:18	29	32	76302	5670	–	–	–	–	
	05	29-01-99	19:34	29	261	9614	2028	–	–	–	–	
	06	29-01-99	20:18	27	96	6632	1881	–	–	–	–	
	07	29-01-99	21:00	27	242	12609	2872	–	–	–	–	
	08	29-01-99	21:44	27	605	17368	3834	–	–	–	–	
	09	29-01-99	22:34	27	441	19980	4107	–	–	–	–	
	10	29-01-99	23:21	27	417	11486	3212	–	–	–	–	
	11	30-01-99	01:12	28	124	27497	5314	–	–	–	–	
	12	30-01-99	01:59	28	127	23697	3902	–	–	–	–	
	13	30-01-99	02:44	27	223	35155	8084	–	–	–	–	
	14	30-01-99	03:30	28	302	31898	5805	–	–	–	–	
	15	30-01-99	04:19	18	754	21153	4520	–	–	–	–	
	16	30-01-99	06:33	28	223	25247	4773	–	–	–	–	
I01	01	27-01-99	15:53	15	0	351	108	11	153	609	369	g
	02	27-01-99	16:15	24	18	518	134	12	94	530	299	g
I02	01	27-01-99	16:49	31	47	437	162	21	57	943	332	g
	02	27-01-99	17:21	30	43	318	139	21	113	441	219	g
I03	01	27-01-99	17:51	31	64	303	162	21	106	518	234	g
	02	27-01-99	18:27	31	63	194	119	22	86	226	141	g
I04	01	04-02-99	06:55	30	18	213	76	22	19	197	76	g
	02	04-02-99	07:27	30	29	263	89	21	53	260	133	g
I05	01	04-02-99	08:06	31	27	355	94	22	25	266	159	g
	02	04-02-99	08:40	30	23	246	122	22	45	473	215	g
I06	01	04-02-99	09:14	30	16	580	149	22	4	530	166	g
	02	04-02-99	09:46	31	26	554	159	22	52	860	230	g
I07	01	04-02-99	10:25	31	23	365	102	22	41	451	161	g
	02	04-02-99	10:57	31	15	748	165	22	58	1010	229	g
I08	01	04-02-99	11:24	–	–	–	–	20	19	555	138	g
	02	04-02-99	11:53	–	–	–	–	17	31	1460	263	g



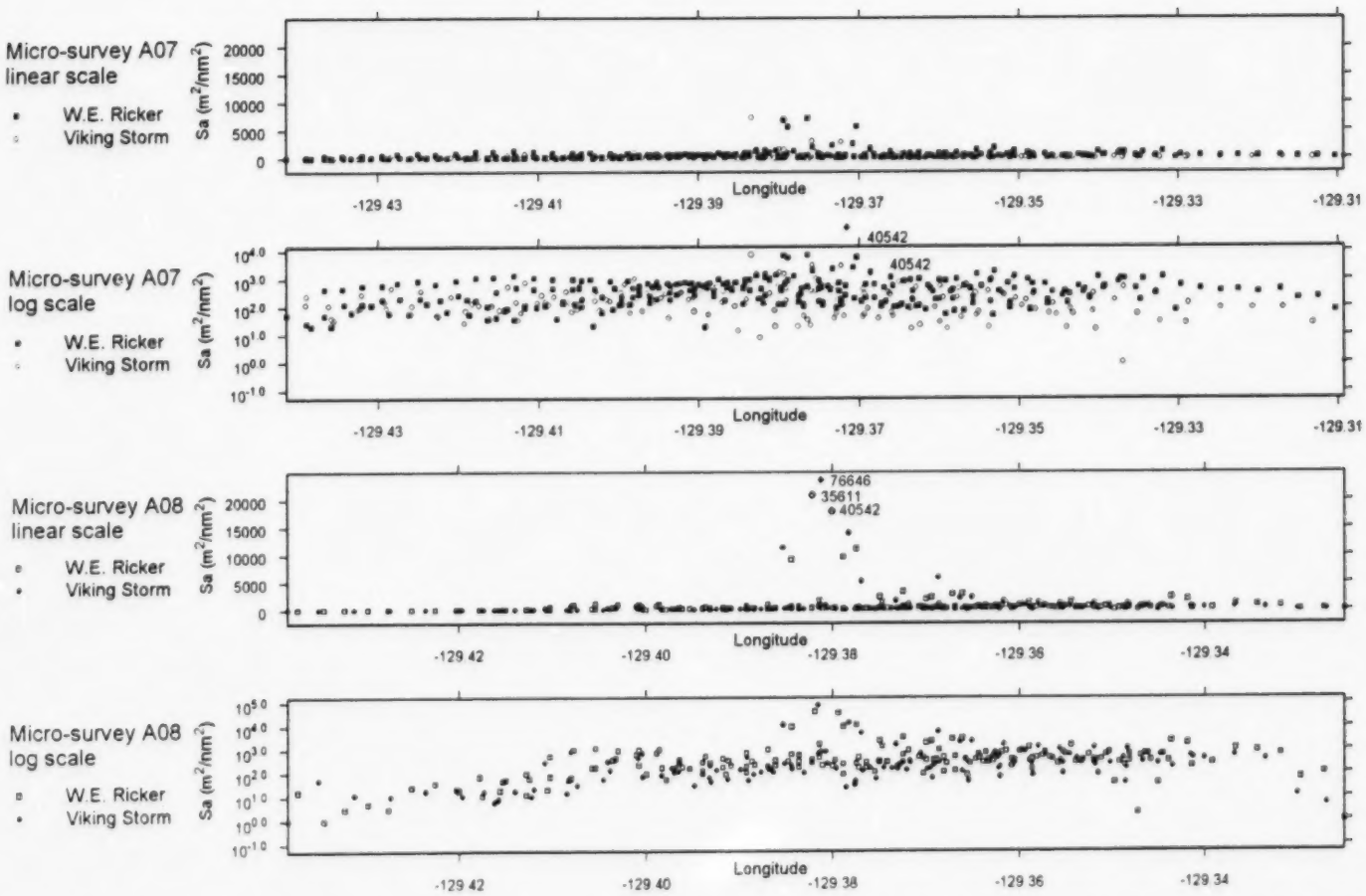
Appendix Figure 1a. SaI values plotted on both linear and logarithmic scales against their longitudinal positions at the Triangle Island study site (A). All SaI values for all transects in micro-surveys 1 and 2 are shown. Values from the W.E. Ricker are squares while the Viking Storm values are circles. The leading vessel values are shown with filled symbols, while the following vessel has open symbols. On the linear scale plots, SaI values greater than the axis maximum (25,000 m^2/nm^2) are indicated by diamonds with the associated value.



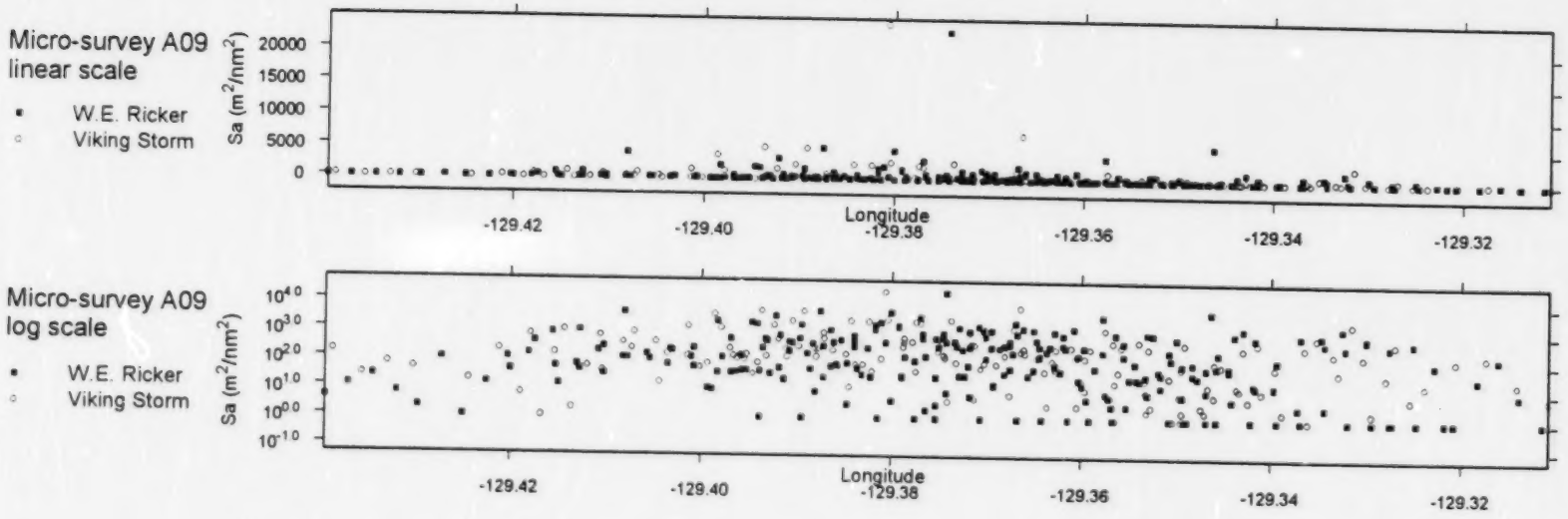
Appendix Figure 1b. SaI values plotted on both linear and logarithmic scales against their longitudinal positions at the Triangle Island study site (A). All SaI values for all transects in micro-surveys 3 and 4 are shown. Values from the W.E. Ricker are squares while the Viking Storm values are circles. The leading vessel values are shown with filled symbols, while the following vessel has open symbols. On the linear scale plots, SaI values greater than the axis maximum (25,000 m^2/nm^2) are indicated by diamonds with the associated value.



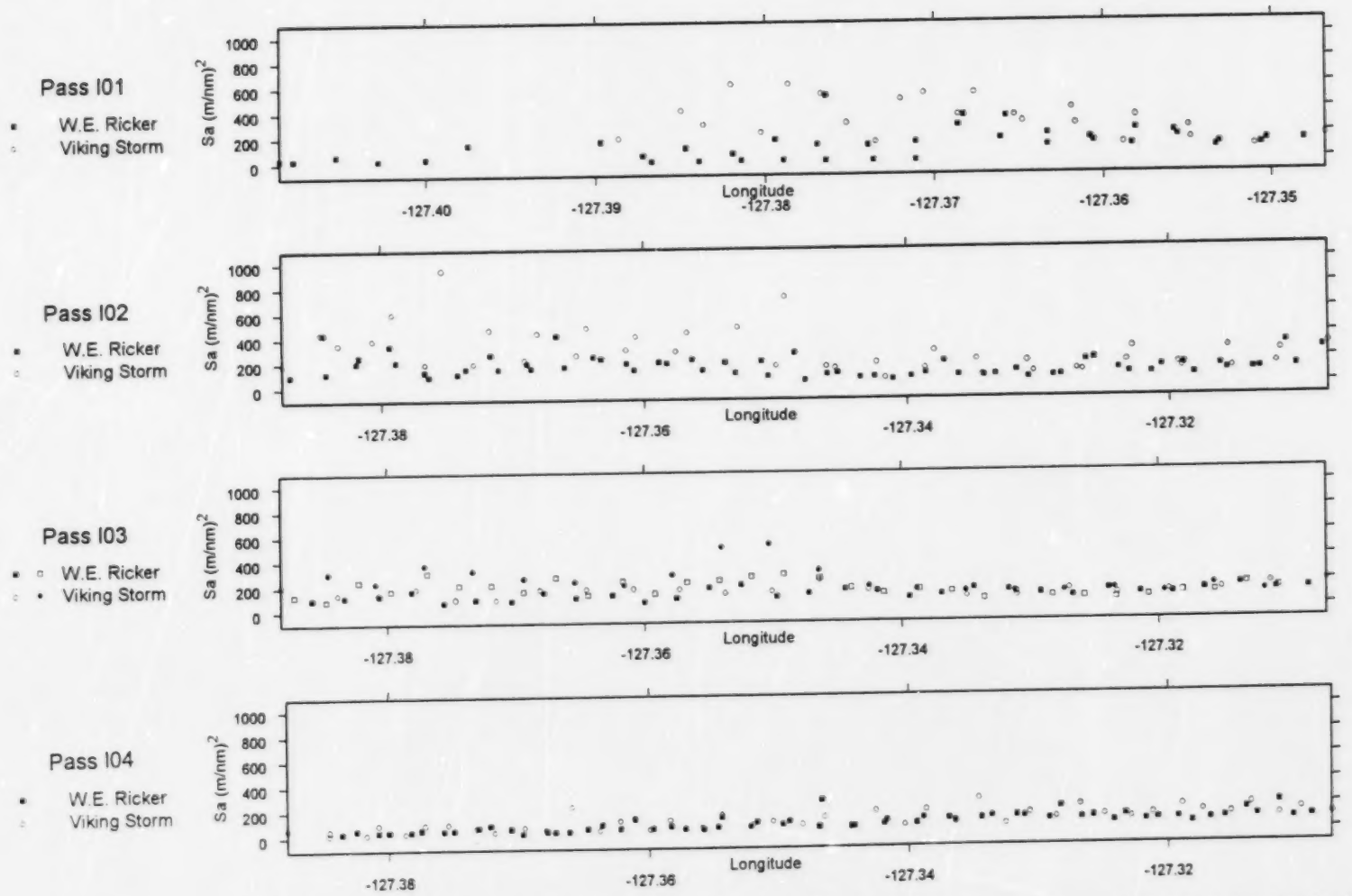
Appendix Figure 1c. SaI values plotted on both linear and logarithmic scales against their longitudinal positions at the Triangle Island study site (A). All SaI values for all transects in micro-surveys 5 and 6 are shown. Values from the W.E. Ricker are squares while the Viking Storm values are circles. The leading vessel values are shown with filled symbols, while the following vessel has open symbols. On the linear scale plots, SaI values greater than the axis maximum (25,000 m^2/nm^2) are indicated by diamonds with the associated value.



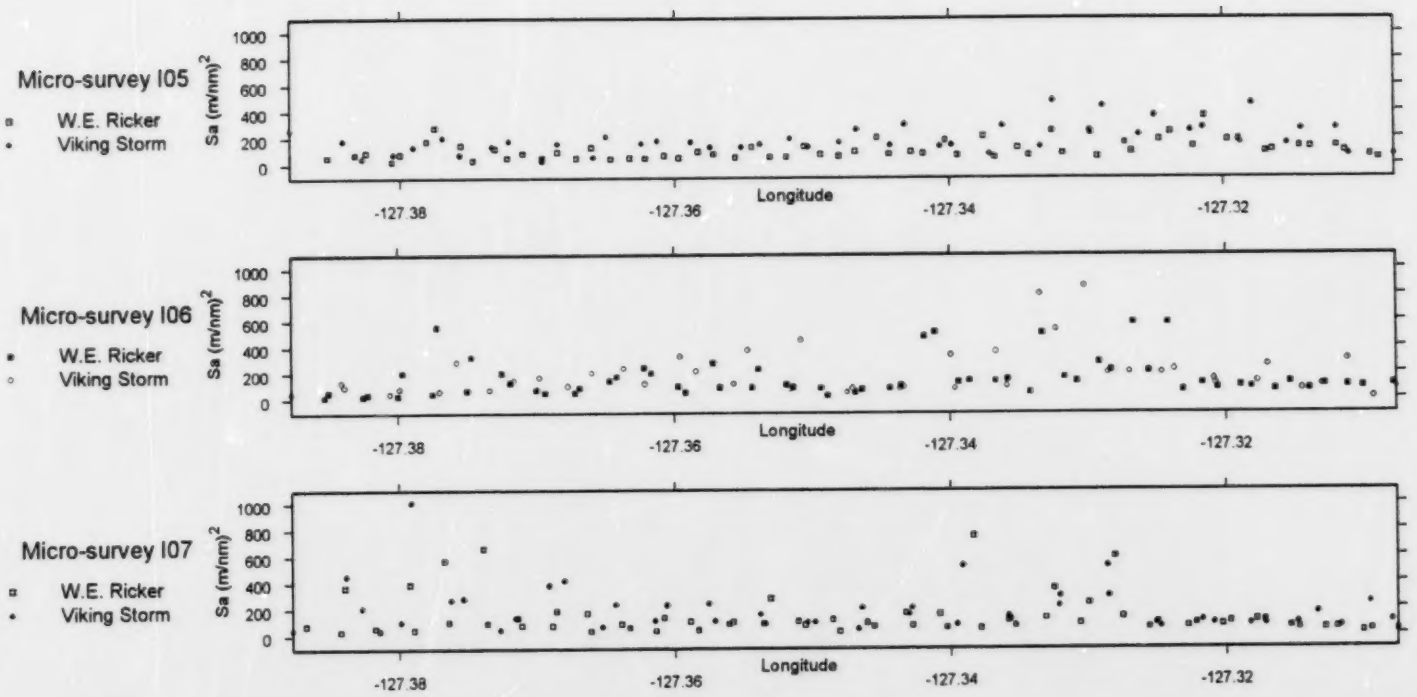
Appendix Figure 1d. Sal values plotted on both linear and logarithmic scales against their longitudinal positions at the Triangle Island study site (A). All Sal values for all transects in micro-surveys 7 and 8 are shown. Values from the W.E. Ricker are squares while the Viking Storm values are circles. The leading vessel values are shown with filled symbols, while the following vessel has open symbols. On the linear scale plots, Sal values greater than the axis maximum (25 000 m^2/nm^2) are indicated by diamonds with the associated value.



Appendix Figure 1e. SaI values plotted on both linear and logarithmic scales against their longitudinal positions at the Triangle Island study site (A). All SaI values for all transects in micro-survey 9 are shown. Values from the W.E. Ricker are squares while the Viking Storm values are circles. The leading vessel values are shown with filled symbols, while the following vessel has open symbols.



Appendix Figure 2a. SaI values plotted on linear scales against their longitudinal positions at the Goletas Channel study site (I). All SaI values for all transects in micro-surveys 1 through 4 are shown. Values from the W.E. Ricker are squares while the Viking Storm values are circles. The leading vessel values are shown with filled symbols, while the following vessel has open symbols. Note that during micro-survey I03, the Viking Storm led transect 1 while the W.E. Ricker led transect 2.



Appendix Figure 2b. SaI values plotted on linear scales against their longitudinal positions at the Goletas Channel study site (I). All SaI values for all transects in micro-surveys 5 through 7 are shown. Values from the W.E. Ricker are squares while the Viking Storm values are circles. The leading vessel values are shown with filled symbols, while the following vessel has open symbols.